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MIC IMPACT OF HIGHWAY SNOW AND ICE CONTROL

State-of-the-Art

DEPARTMENT OF TRANSPORTATION ★ UNITED STATES OF AMERICA ★

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Interim Report

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UTAH
DOT

FOREWORD

This report is a summary of some of the more important literature on highway snow and ice control. It will be of interest to all concerned with the economic, operational, and environmental aspects of winter maintenance.

The report was prepared as part of a study entitled "Economic Impact of Highway Snow and Ice Control" conducted for the Federal Highway Administration, Office of Research, Washington, D.C. under Contract DOT-FH-11-8580. All original research conducted under this contract will be documented in the forthcoming final report.

Sufficient copies of the present report are being distributed to provide a minimum of four copies to each FHWA Regional office, one copy to each FHWA Division office, and one copy to each State highway agency. Direct distribution is being made to the Division offices.

Charles F. Scheffey

Charles F. Scheffey
Director, Office of Research
Federal Highway Administration

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16 ABSTRACT

This report contains a State-of-the Art for the economics of highway snow and ice removal. The State-of-the-Art covers maintenance, traffic, safety, environment, roadway damage, vehicle corrosion, structural deterioration and economic analyses.

In the maintenance portion, an indepth review of public relations, public opinion, sovereign immunity, procedures, materials and equipment is presented.

The economic impact of snow and ice on traffic and safety is covered thru traffic volume changes, fuel consumption, tardiness, comfort and convenience.

The environmental section is mainly concerned with the effects of deicing salts on the environment. Alternative materials and methods are also reviewed.

The consequence of snow and ice removal on pavement paint strips and pavement markers is covered under pavement damage.

The problems related to vehicle corrosion and bridge deterioration are examined.

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CHAPTER I

INTRODUCTION

by: Bob H. Welch

Public demand for clean highways along with funding limitations and the ever-increasing cost of maintenance [1] has brought about the need to assimilate a comprehensive review of literature, research and experience for the highway administrator concerning the economics of highway snow and ice control. The administrator is frequently called on to make economic decisions before allocating funds for specific purposes. The final decision may be based on social, educational, political or other non-economic factors, but if his budget can be justified economically, he has a far greater chance of obtaining public support for the measures finally recommended or utilized. One area where such economic justification would be particularly helpful is in recommending budgets for snow and ice removal. Each year governments spend significant sums of money to counteract the adverse effects of ice and snow. Although such expenditures have appeared necessary in the interest of public safety, there is a limit to the amount that can be spent and remain justified [2]. The problem of budget limitations is not unique to maintenance engineers. The problem is made more serious by convincing estimates of economic losses, associated with variances in snow removal strategies, based on the use of highly questionable statistics [3].

Administrators, engineers, and researchers are faced continually with highway problems on which much information already exists either in documented form or in terms of undocumented experience and practice. Unfortunately, this information often is fragmented, scattered, and unevaluated. As a consequence, full use of information on what has been learned about a problem is not assembled in seeking a solution [4], or used in making decisions.

This report attempts to synthesize in a comprehensive manner the relevant and significant information from research and experience. This requires a basic review of many areas including environmental impact, levels of service, traffic characteristics, maintenance activities, legal responsibilities, automobile corrosion, bridge deck deterioration and public opinion.

There exists in the literature concerning snow and ice maintenance and the corresponding economic effects a vast amount of information. Much of this is repetitive or only covers fragmentary excerpts from other sources. Therefore to maintain this report to a manageable size, significant literature, practices and experience that yields a comprehensive review is included with references to other sources that have reported similar results. An index listings is included to allow this document to be exercised as a reference volume for specific subject matter, independent of the text as a whole.

CHAPTER II

ECONOMIC ANALYSIS

by: Cherng C. Sy

This chapter presents an overview of general methods of economic analysis. There are several methods of economic analysis: the annual cost method, the present worth method, the rate of return method, the benefit-cost method, and the break even analysis. The relative merits, demerits and limitations of these concepts are discussed in references [5], [6], and [7]. The marginal analysis of benefits and costs will be used as an example to illustrate the economics of highway snow and ice control. A brief review of some of the economic cost functions in winter maintenance are presented.

In the private sector of the economy, fair price and level of output can be determined by the competitive forces of supply and demand. Whereas in the public sector of the economy, publicly produced goods such as a network of highways cannot be handled through the private market mechanism because of the indivisibility and the interdependency of the highway system. Moreover, profit motivation fails to yield an optimum level of quality and quantity in public works. The purpose of investment for a private industry is to make the largest profit possible; public expenditure on a highway related project, however, is earmarked to maximize the benefit to the community which cannot be parceled out among members of the community by the private market mechanism in any satisfactory manner. Therefore, comparison of the total costs and the total benefits is essential to decide whether a specific highway project should be undertaken [8], [9], [10], [11], [12], and [13].

The first major application of benefit and cost analysis was found in the Flood Control Act of 1936 which requires that the benefits must exceed the costs for any water resources project. In recent years, government activities and expenditures have increased steadily, benefit and cost analysis has extended to public works in all fields. It is used as a major criterion in the economic analysis of transportation. The two leading publications in the field of highway economic analysis, "Summary and Evaluation of Economic Consequences of Highway Improvement" [14], and "Road User Benefit Analysis for Highway Improvements" [15] have recommended the use of benefit and cost analysis for highway decision making.

For this general discussion of economic analysis in winter maintenance, two perspectives will be discussed: (1)- an analysis at each component level and (2)- for the project as a whole.

(1) For each individual segment of the project, the marginal anlaysis of economic theory would suggest that the level of winter maintenance activity should be carried to a point where the incremental benefit is equal to the incremental cost, i.e., (incremental benefit/incremental cost) = 1. To illustrate this point, assume all of the functions $B(X)$, $C(X)$ and $W(X)$ are differentiable. Let X represent levels of service, $B(X)$ the benefit function (including all direct and indirect benefits), $C(X)$ the cost function and, $W(X)$ the welfare function of the community, where $W(X) = B(X) - C(X)$.

In order to maximize $W(X)$, it is necessary that the first derivative $W'(X)$ be zero i.e., first derivative $B'(X) = C'(X)$ or marginal benefit = marginal cost (where $W'(X)$, $B'(X)$ and $C'(X)$ are the first derivative of $W(X)$, $B(X)$ and $C(X)$ respectively)* [16].

In a benefit and cost analysis of winter maintenance, the first task is to quantify the benefits and costs associated with the economic, safety and environmental aspects of each feasible plan. The benefits from each plan are the sum of all prospective reductions in economic loss, risk cost, operating cost, time delay cost, fire losses, and so forth; the costs from each plan are the sum of all direct material cost (such as abrasives and chemicals), spreading cost, plowing cost, enviromental cost, vehicle corrosion cost, cost of bridge deck deterioration, etc. The detailed discussion of this will be presented in the maintenance, enviromental, vehicle corrosion, traffic and safety chapters. The second task is to compare the different levels of improvement (or plans) successively beginning with the null situation (or do nothing situation) [5], [6] and [17].

The following illustrative examples demonstrate the simple idea of marginal analysis when the benefit-cost ratio is used.

Tables 1, 2, and 3 illustrate the manner in which plans are evaluated in the order of increasing cost. It is obvious that a new plan should not be adopted unless its incremental benefit (or marginal benefit) is at least equal to the corresponding incremental cost (marginal cost). The activity should be carried to a point where this marginal benefit equals the marginal cost (i.e., the incremental benefit-cost ratio is one) whenever economically feasible. Plan 1 is superior to plan 0 (do nothing) on the basis of its incremental B/C ratio of 3.0. Plan 2 is superior to plan 1 because its incremental B/C ratio is 2.10, an improvement over plan 1. Plans 3, 4, and 5 are all abandoned because their incremental B/C ratio for plan 2 is less than unity. It follows that plan 2 is the best choice which provides the maximum net benefit of 155 (Table 2), and a minimum total cost of 445 (Table 1).

---

*This is the necessary condition for an optimal solution. The sufficient condition requires that the second derivative $W''(X)$ be ≤ 0. The second order condition essentially means that we are at the point of decreasing net returns to scale.

TABLE 1: COST COMPARISON FOR VARIOUS WINTER MAINTENANCE PLANS (5)

Maintenance Plan	Total Annual Cost (dollars)	Total Annual Loss Due to Storms (dollars)	Total Overall Cost (dollars)
0 (Do Nothing)	0	600	600
1	50	450	500
2	100	345	445 (min.)
3	150	300	450
4	200	275	475
5	250	260	510

TABLE 2: COMPARISON OF BENEFIT-COST RATIOS (5)

Maintenance Plan	Annual Cost (dollars)	Annual Benefit (dollars)	Benefit-Cost Ratio	Net Benefit (Total Benefit-Total Cost) (dollars)
1	50	600-450 = 150	3.00	100
2	100	600-345 = 255	2.55	155 (max.)
3	150	600-300 = 300	2.00	150
4	200	600-275 = 325	1.62	125
5	250	600-260 = 340	1.36	90

TABLE 3: CALCULATION OF INCREMENTAL BENEFIT-COST RATIOS (5)

Maintenance Plan Compared	Incremental Annual Cost (dollars)	Incremental Annual Benefit (dollars)	Incremental Benefit-Cost Ratio
1 over 0	50	150	3.00
2 over 1	50	105	2.10
3 over 2	50	45	0.90
4 over 2	100	70	0.70
5 over 2	150	85	0.57

From Table 2, "Comparison of Benefit-Cost Ratio" the benefit cost ratio for maintenance plan 5 is 1.36. This means that for every unit of dollar resources invested, there will be 1.36 units of benefit, a seemingly wise course of action. However, when subjected to incremental benefit cost analysis, this plan evolves as the worst possible choice, the lowest net benefit of 0.90 occurs.

(2) For the project as a whole, in order to attain the maximum benefit from snow and ice control projects, the allocation of limited resources to each activity should be such that the incremental benefit/cost ratio for each area of the project must be the same ie,

$$\frac{\Delta B_1}{\Delta C_1} = \frac{\Delta B_2}{\Delta C_2} = \qquad \frac{\Delta B_n}{\Delta C_n} \qquad (\underline{1})^*$$

(assuming the project consists of n areas). If this condition is not satisfied, the project engineer can benefit by merely shifting resources from low incremental benefit-cost ratio areas to high areas. For example, if the incremental benefit-cost ratio in the environmental area is one and the incremental benefit-cost ratio in the traffic and safety area is three, then by transferring one unit of cost from the environmental area to the traffic and safety area would result in a net gain of two units of benefit [18].

Regression equations have been used to predict snow and ice removal expenditures.

(a) Single Equation Model

Ohio State Department of Highways used data for three years, 1967, 1968 and 1969 to develop regression equations. The model predicts the cost for snow and ice control in each county based on 30-years of average snowfall data and current average daily traffic (ADT) values for each county. The study indicates that the two most significant independent variables affecting cost per lane-mile for snow and ice removal (henceforth known as "y") are inches of snowfall (X_1) and ADT (X_2), or written in mathematical form:

$$y = F(X_1, X_2) \qquad (2)$$

The multiple correlation coefficient (R) varies from 0.6 to 0.8, therefore the multiple coefficient of determination varies from 0.36 to 0.64 (ie, approximately 36% to 64% of the variations in the dependent variable is explained by the equation) [19].

In the Single Equation Model Case, variables are classified as either independent or dependent. Under the conditions that are specified in the assumptions of the Model, ordinary least squares method would yield the Best Linear Unbiased Estimators (BLUE).

---

*Δ Indicates incremental quantities

(b) Simultaneous System of Equations

Dunlay in his article "A Simultaneous Equation Econometric Model of Winter Maintenance Cost Categories" [20] has pointed out the inadequacy of the Single Equation Model where several categories of winter maintenance expenditures are considered. Here the variables are characteristic of a county, such as the ratio of mileage of four or more lanes to total mileage (X_1), ruggedness (X_2), climate (X_3), traffic (X_4), etc.; their values are determined outside the system of equations. The endogenous variables are winter maintenance expenditures, such as expenditures on abrasives (Y_1), deicing chemicals (Y_2), spreading costs (Y_3), etc. their values are determined within the model. The purpose of this model is to predict winter maintenance expenditures (endogenous variables) based on the characteristics of a county (exogenous variables).

Thus, written in mathematical form:

$$Y_1 = F(Y_2, Y_3, --- Y_i, X_1, X_2, ---, X_j) \qquad (3)$$

$$Y_2 = F(Y_1, Y_3, --- Y_i, X_1, X_2, ---, X_j) \qquad (4)$$

$$Y_i = F(Y_1, Y_2, Y_3, --- Y_i-1, X_1, X_2, ---, X_j) \qquad (5)$$

Where Y's are endogenous variables, and X's are exogenous variables.

If the ordinary least square or generalized least squares method is used in a simultaneous system of equations, either would yield biased and inconsistent estimators because the random error could no longer satisfy the assumption that they should be independent of the regressors. These methods are being asked to do more than they were designed for.

If the model is mathematically complete, if the necessary and sufficient conditions for identification are met, and if there is no statistical problems of multicollinearity, then the two-stage least squares method would yield consistent estimators [21] and [22].

CHAPTER III

MAINTENANCE

by: Bob H. Welch and Forrest R. McConkie

Introduction

Maintenance activities as they relate to highway snow and ice control are aimed at providing the highway user a service, a service which has been traditionally justified on the basis of user savings, politics, or convenience. These savings have taken the form of additional safety, less fuel consumption, less traffic delay and congestion, and even the decrease in production loss due to tardiness, absenteeism and product spoilage. With one or more of these goals set by service agencies representing governments at all levels and even toll authorities, it would seem that once the level of service or goal has been determined for a particular highway that the procedures to attain that goal would be somewhat consistent.

This is certainly not the case. From one highway agency to another there are considerable differences in policy, equipment inventories, types of equipment, manpower allocations, material types and amounts used, budgeting procedures, accounting procedures and the means of determining snow and ice removal productivity. Some of the differences are even notable between districts within one state, usually accompanied by "every situation is unique." Nowhere else in highway maintenance activities are the uniqueness or differences of procedure and equipment so notable as in snow and ice control.

Geographic locations subjected to winter storms are populated with a public very much aware of efforts being placed on snow removal. Snow and ice control is an obvious service to the driving public and consequently there exists in many areas a level of effort given to snow and ice control based on real or assumed public demand. Since a large percentage of state highway maintenance budgets in areas where a severe winter climate must be contended with is allocated to the snow removal activity, a summary of public opinion and sovereign immunity is included in this chapter in addition to the nuts and bolts of maintenance activities.

Public Relations

Effective public relations associated with any activity directly or indirectly affecting large groups of people is essential for acceptance or rejection of an otherwise worthy activity.

Maintenance engineers have found that a change in deicing materials used, road closure policies or expected roadway conditions are easier implemented if the general public has prior knowledge of the change and can prepare for it if necessary. Lowering of service levels for snow and ice control together with temporary setbacks in attempts to keep ahead of storms are met with less resistance if these conditions are generally expected.

Particularly in metropolitan areas, maintenance practices that are expected to differ from normal is not so devastating if the local news media have reported information on expected road conditions in addition to weather forecasts. Areas with air traffic watches have found these helpful and cooperative with highway agencies to promote traffic flows in urban communities and avoid delays on slow moving, congested highway segments.

Areas more isolated from urban centers can be potentially hazardous for stranded motorists during snow conditions. An offer to radio help from emergency vehicles or tow trucks promotes a more desirable relationship with the public. Many highway agencies do not allow their maintenance vehicles to aid directly (towing, pushing, etc.) in snow rescue operations. It has been helpful, however, to aid motorists back onto the highway, if possible, upon the driver's desire.

Policies governing proper public relations in most areas of highway work are adopted by the majority of state agencies, and these should not be overlooked in the snow and ice removal activity.

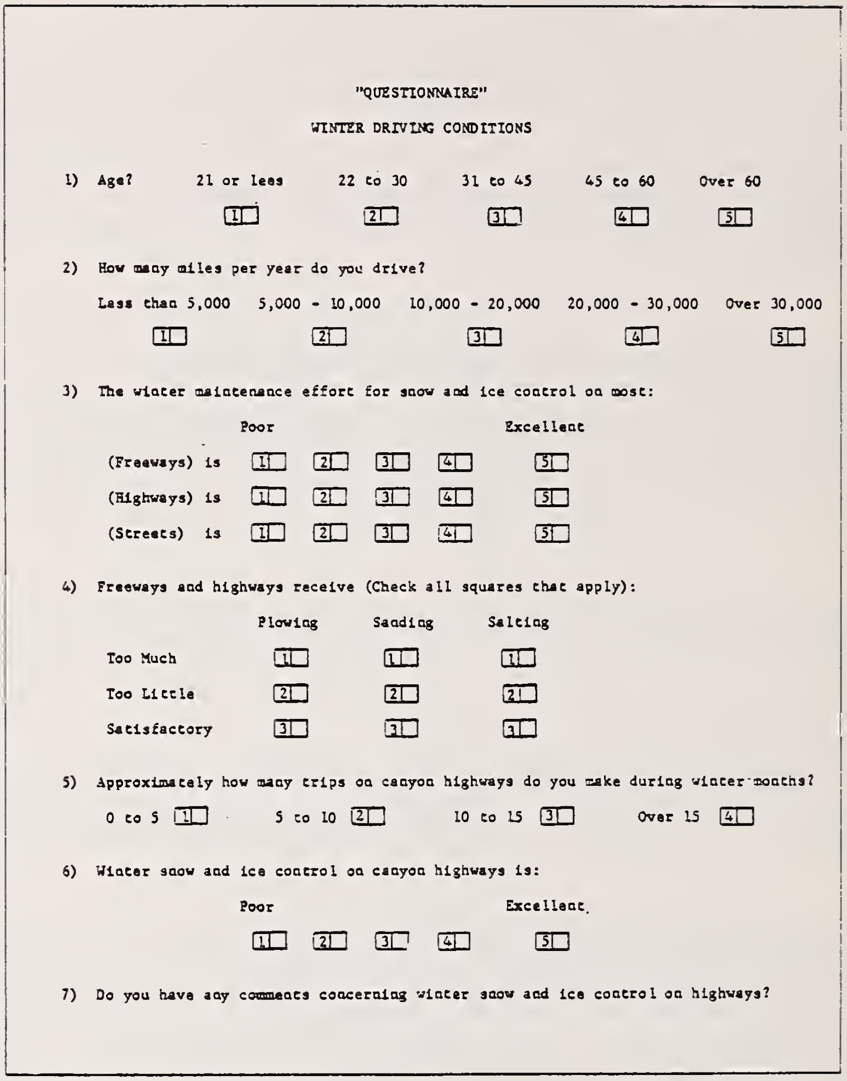
Public Opinion

Ecological considerations and the search for quality in life have focused the spotlight of public interest on maintenance operations of every sort, including those of highway snow and ice control [23].

Figure 1 is a questionnaire used by the Utah Department of Transportation to obtain a response of public attitude towards the level of effort of snow and ice control. An attempt was made to differentiate the attitudes based on highway type, driver age, amount of mountainous driving and number of miles driven. The questionnaire was filled out by applicants renewing drivers license permits over a two week period in January and August for the locations of Salt Lake City (Pop. 1970-175,885), Cedar City (Pop. 1970-8,946), and Brigham City, Utah (Pop. 1970-14,007).

Figures 2 through 30 summarize the results of these questionnaires.

A survey [24], obtaining over 1,200 responses from a cross section of the traveling public, including over-the-road truckers, ranchers, traveling salesmen, rural mailmen, as well as members of the American Automobile Association, State Granges, State Farm Bureau organizations, and other trade organizations was conducted.



"QUESTIONNAIRE"

WINTER DRIVING CONDITIONS

1) Age?

21 or less	22 to 30	31 to 45	45 to 60	Over 60
1☐	2☐	3☐	4☐	5☐

2) How many miles per year do you drive?

Less than 5,000	5,000 - 10,000	10,000 - 20,000	20,000 - 30,000	Over 30,000
1☐	2☐	3☐	4☐	5☐

3) The winter maintenance effort for snow and ice control on most:

	Poor				Excellent
(Freeways) is	1☐	2☐	3☐	4☐	5☐
(Highways) is	1☐	2☐	3☐	4☐	5☐
(Streets) is	1☐	2☐	3☐	4☐	5☐

4) Freeways and highways receive (Check all squares that apply):

	Plowing	Sanding	Salting
Too Much	1☐	1☐	1☐
Too Little	2☐	2☐	2☐
Satisfactory	3☐	3☐	3☐

5) Approximately how many trips on canyon highways do you make during winter months?

0 to 5 1☐ 5 to 10 2☐ 10 to 15 3☐ Over 15 4☐

6) Winter snow and ice control on canyon highways is:

Poor				Excellent
1☐	2☐	3☐	4☐	5☐

7) Do you have any comments concerning winter snow and ice control on highways?

FIGURE 1: UTAH DEPARTMENT OF TRANSPORTATION PUBLIC OPINION QUESTIONNAIRE

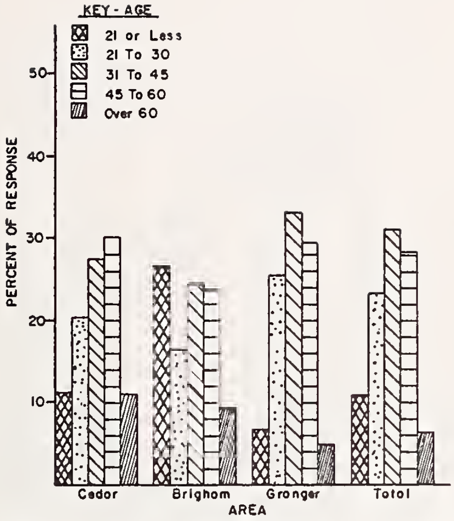


FIGURE 2: AGE OF DRIVER - PERCENT OF RESPONSE BY AREA

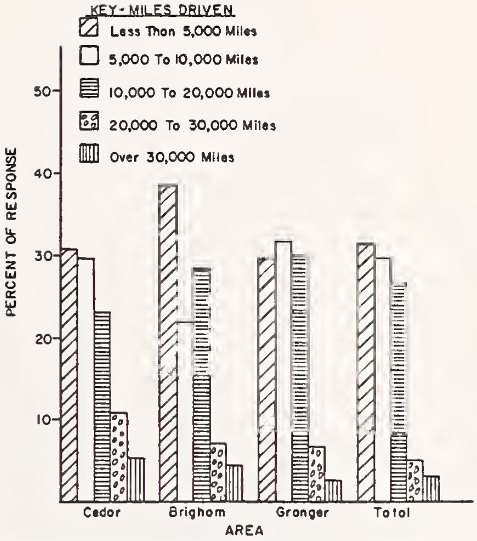


FIGURE 3: MILES DRIVEN PER YEAR - PERCENT OF RESPONSE BY AREA

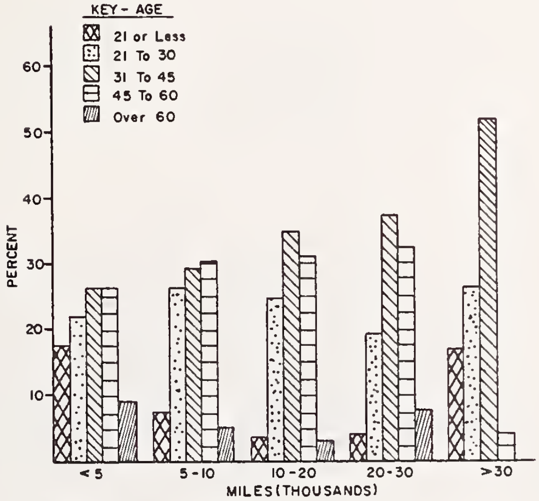


FIGURE 4: CROSS TABULATION - AGE TO MILES DRIVEN

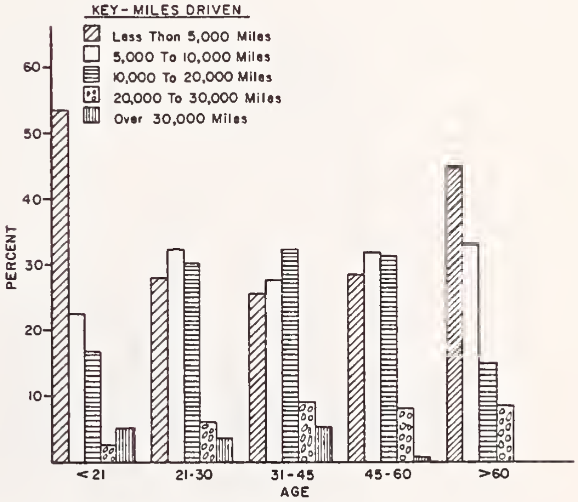


FIGURE 5: CROSS TABULATION - MILES DRIVEN TO AGE

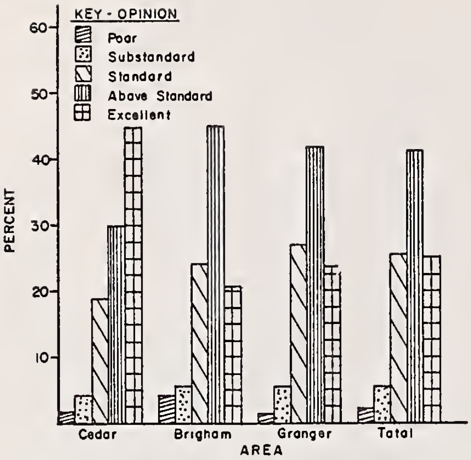


FIGURE 6: OPINION OF WINTER MAINTENANCE ON FREEWAYS - BY AREA

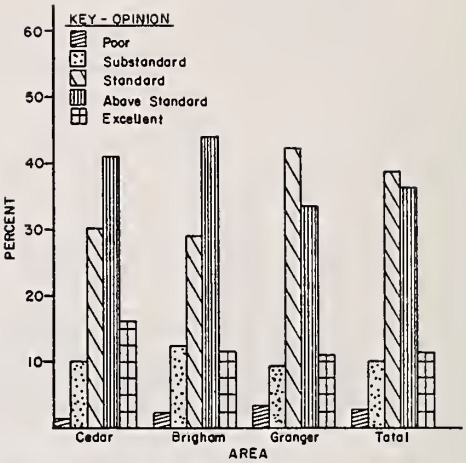


FIGURE 7: OPINION OF WINTER MAINTENCE ON HIGHWAYS - BY AREA

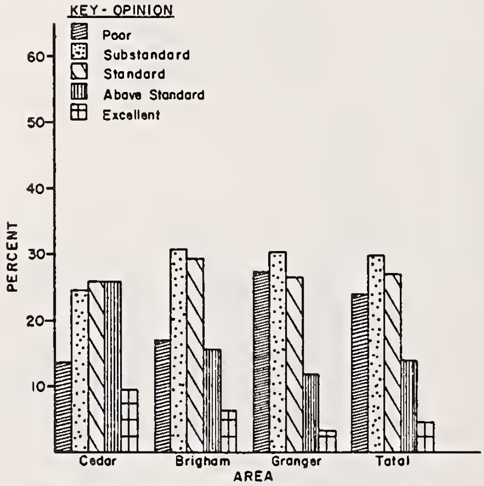


FIGURE 8: OPINION OF WINTER MAINTENANCE ON STREETS - BY AREA

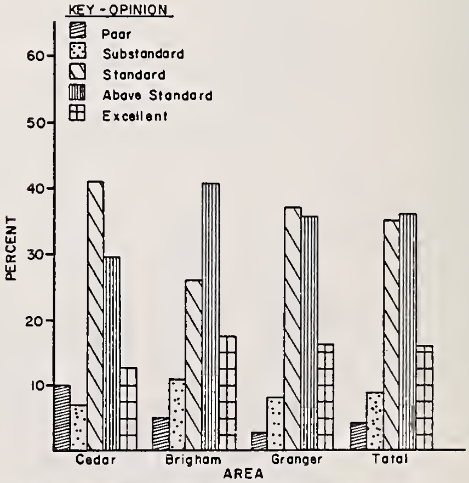


FIGURE 9: OPINION OF WINTER MAINTENANCE ON CANYON ROADS - BY AREA

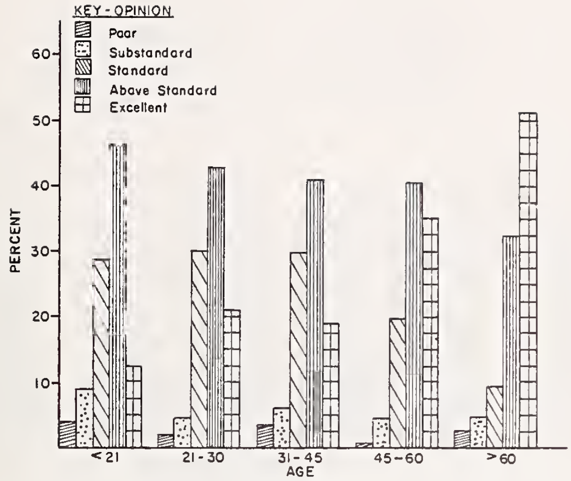


FIGURE 10: OPINION OF WINTER MAINTENANCE ON FREEWAYS BY AGE

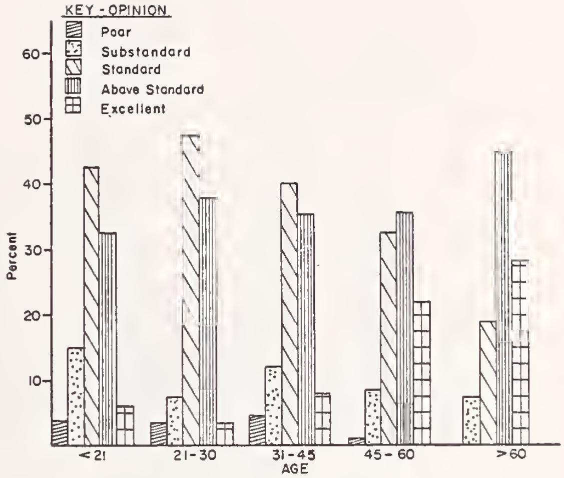


FIGURE 11: OPINION OF WINTER MAINTENANCE ON HIGHWAYS BY AGE

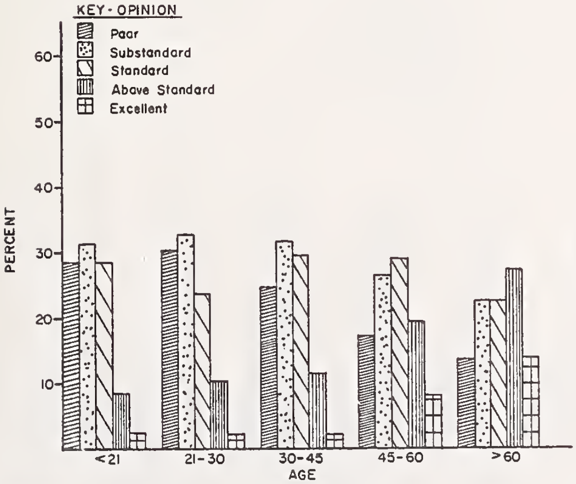


FIGURE 12: OPINION OF WINTER MAINTENANCE ON STREETS BY AGE

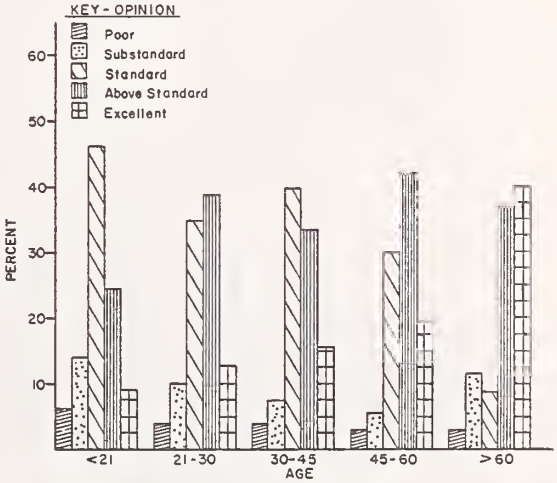


FIGURE 13: OPINION OF WINTER MAINTENANCE ON CANYON ROADS BY AGE

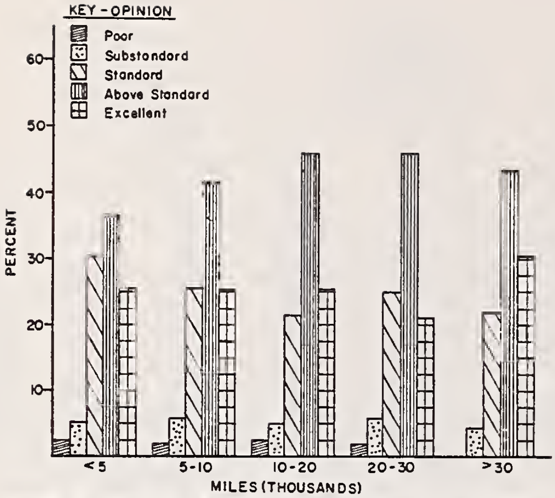


FIGURE 14: OPINION OF WINTER MAINTENANCE ON FREEWAYS BY MILES DRIVEN

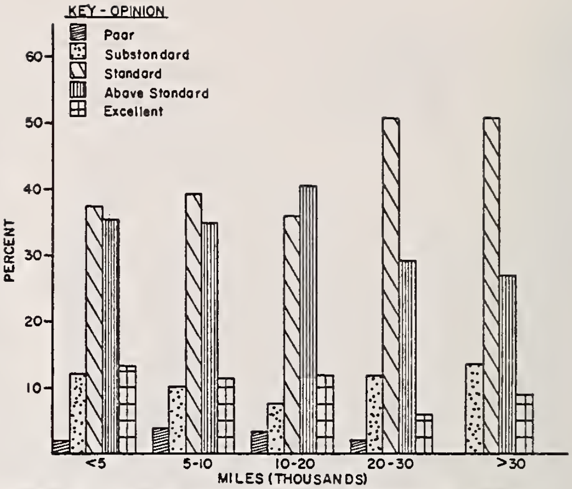


FIGURE 15: OPINION OF WINTER MAINTENANCE ON HIGHWAYS BY MILES DRIVEN

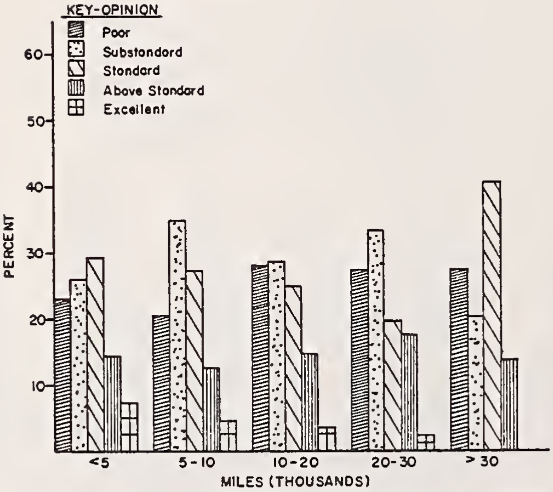


FIGURE 16: OPINION OF WINTER MAINTENANCE ON STREETS BY MILES DRIVEN

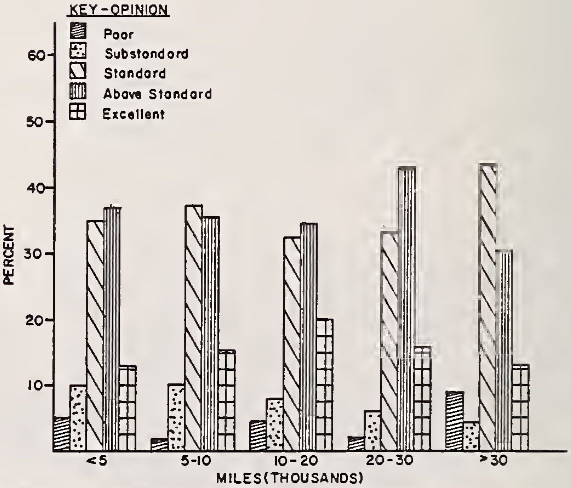


FIGURE 17: OPINION OF WINTER MAINTENANCE ON CANYON ROADS BY MILES DRIVEN

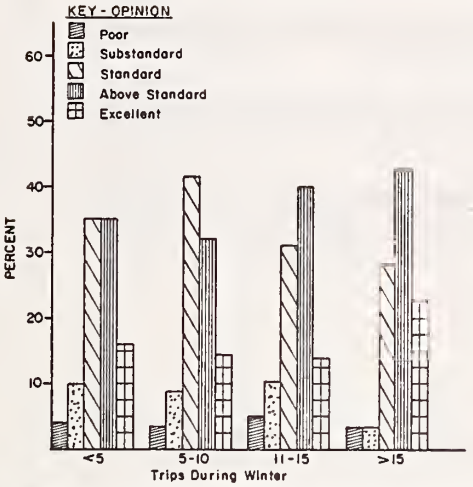


FIGURE 18: OPINION OF WINTER MAINTENANCE ON CANYON ROADS BY NUMBER OF TRIPS

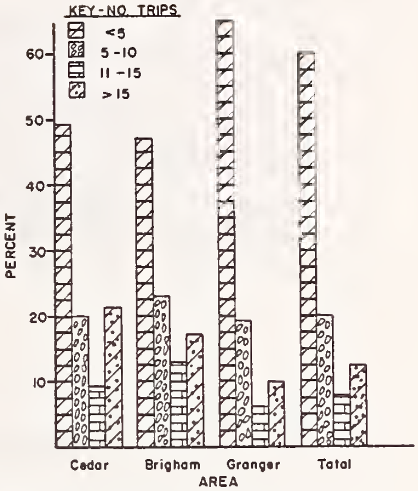


FIGURE 19: NUMBER OF TRIPS ON CANYON ROADS DURING WINTER - BY AREA

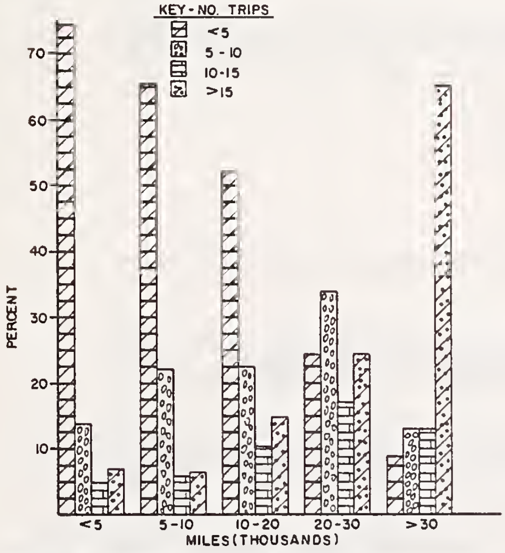


FIGURE 20: NUMBER OF TRIPS ON CANYON ROADS DURING WINTER - BY MILES DRIVEN

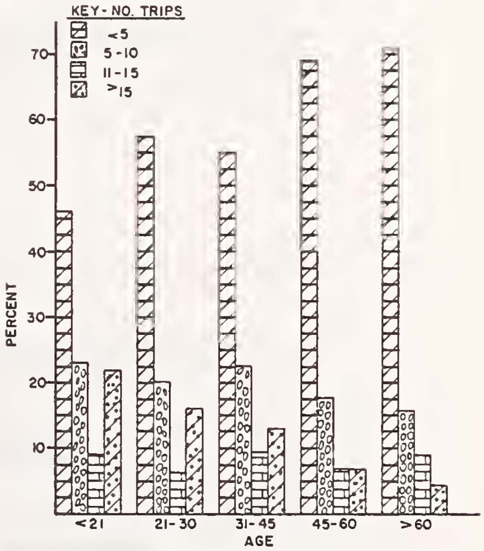


FIGURE 21: NUMBER OF TRIPS ON CANYON ROADS DURING WINTER - BY AGE

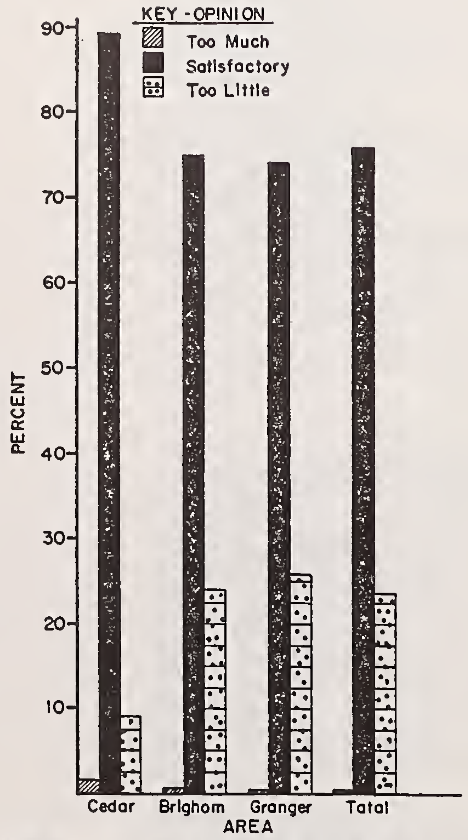


FIGURE 22: OPINION OF AMOUNT OF PLOWING - BY AREA

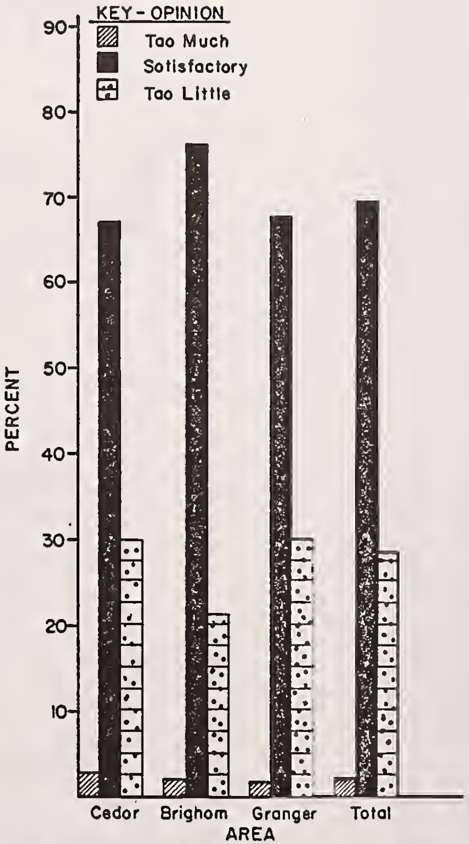


FIGURE 23: OPINION OF AMOUNT OF SANDING - BY AREA

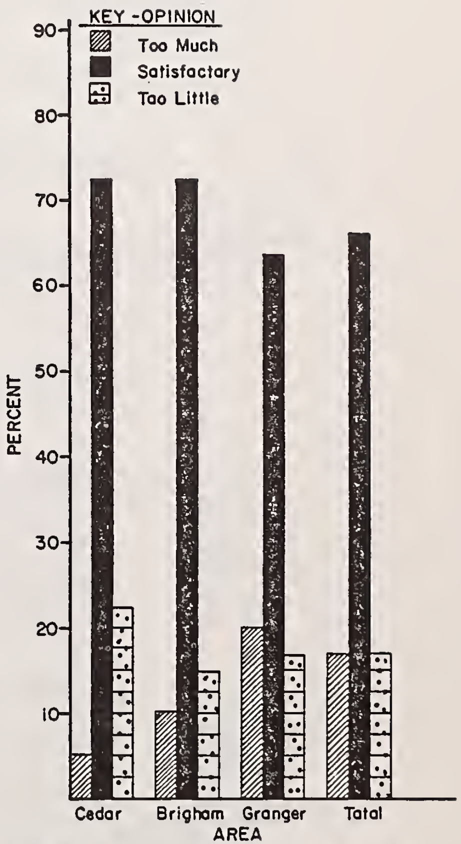


FIGURE 24: OPINION OF AMOUNT OF SALTING - BY AREA

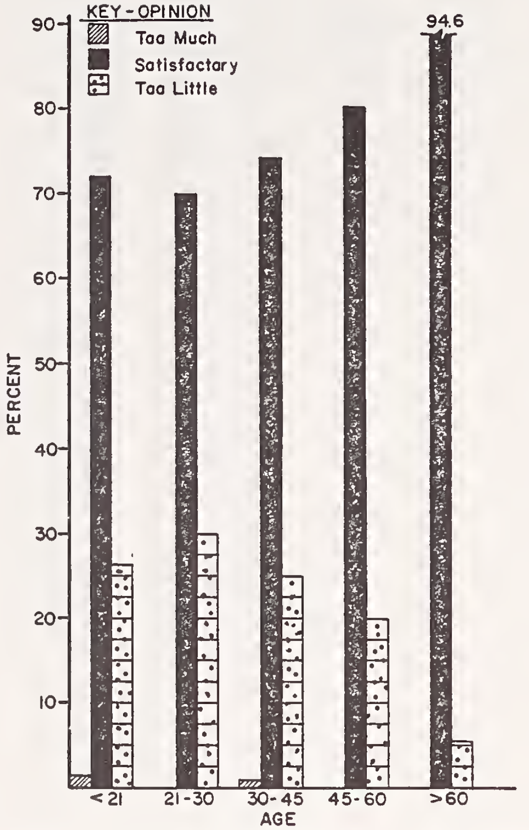


FIGURE 25: OPINION OF AMOUNT OF PLOWING BY AGE

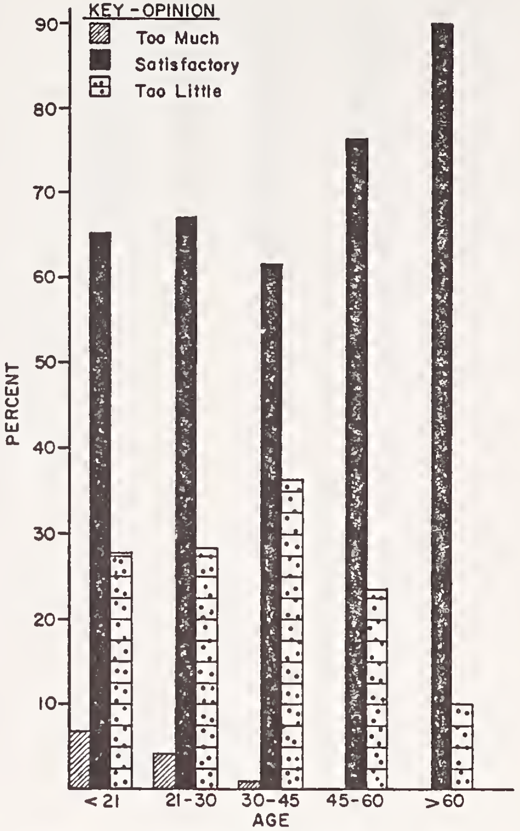


FIGURE 26: OPINION OF AMOUNT OF SANDING BY AGE

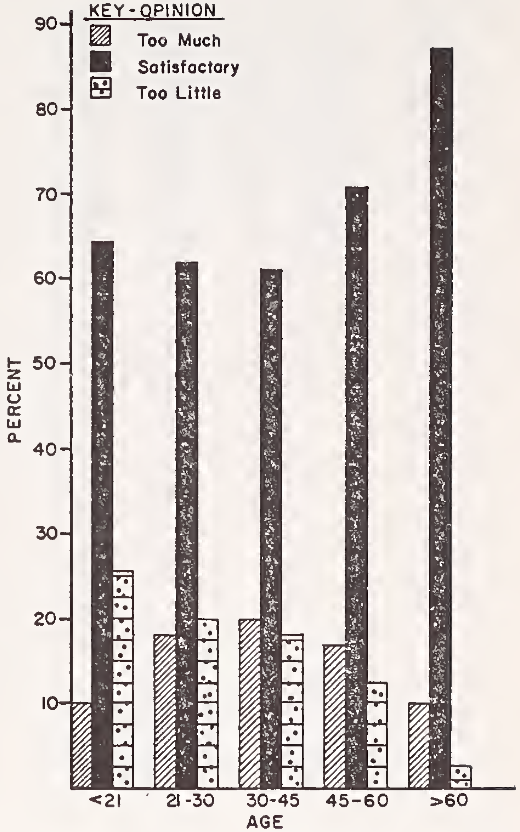


FIGURE 27: OPINION OF AMOUNT OF SALTING BY AGE

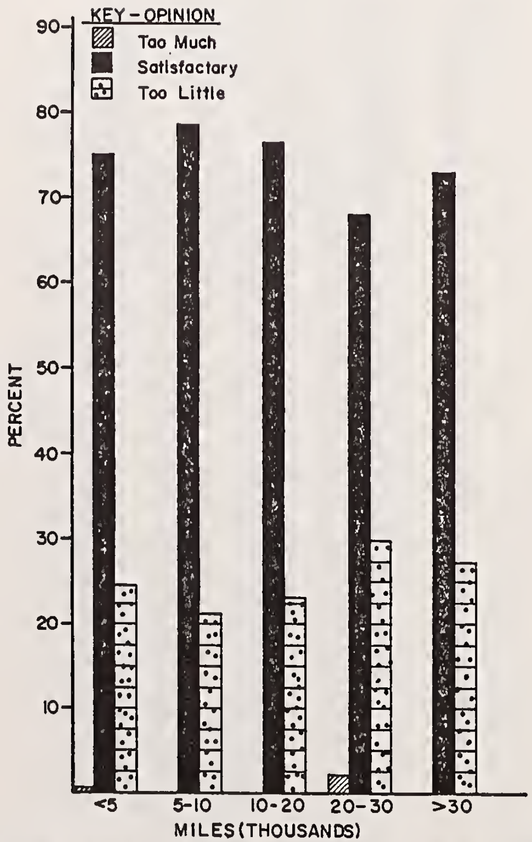


FIGURE 28: OPINION OF AMOUNT OF PLOWING BY MILES DRIVEN

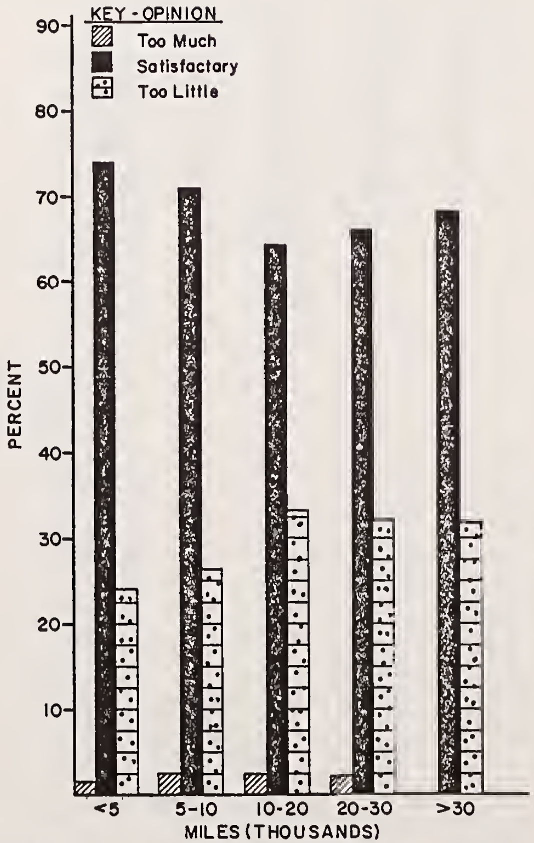


FIGURE 29: OPINION OF AMOUNT OF SANDING BY MILES DRIVEN

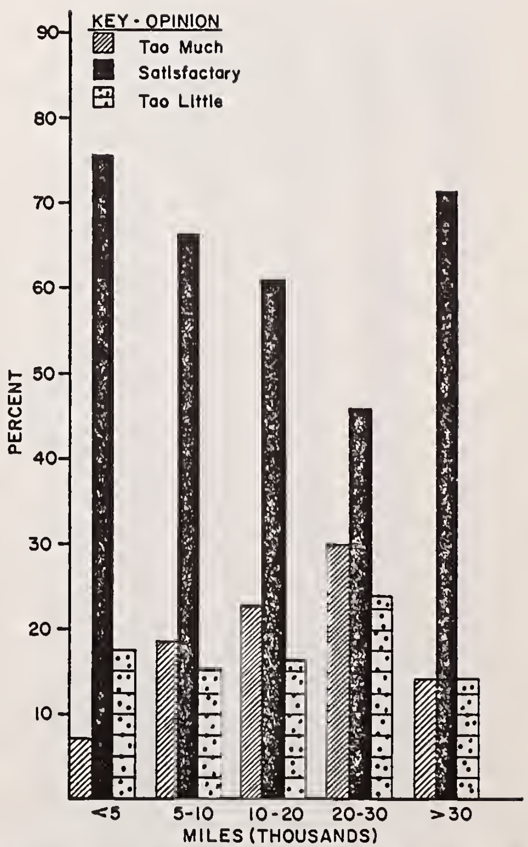


FIGURE 30: OPINION OF AMOUNT OF SALTING BY MILES DRIVEN

Summarizing, the nationwide results of the survey indicated 52 percent felt that highway conditions were allowed to deteriorate before remedial action was taken. Nationwide, two-thirds of the persons surveyed thought that states were doing a good job of snowplowing with about the right existing effort. Of the 30 percent who indicated the rating of "Poor, More Effort Required," many of the responses in this rating came from persons residing in the "border" snow states or parts of southern states which are infrequently subjected to heavy snowfalls.

As to the states' use of chemicals in the form of salt and calcium chloride on the highway, the survey did not specifically question the policy of "bare pavements." However, two-thirds of the respondents thought the states were providing good service with about the right amount of effort being expended; 21 percent rated the activity as "Poor, More Effort Required," but 14 percent thought states were expending too much effort. From those persons residing in the northern tier of "snow-belt" states, about one-fifth of the responses indicated that the states were providing too much effort and too much salt and calcium chloride in controlling snow and ice.

California, in their efforts to evaluate bare pavement snow removal policy, held "150 interviews in ten different locations within the state where" snow removal and deicing activities are prevalent [25]. Only results from respondents who indicated they have driven on the highways during icy or snowy road conditions are reported. In general, the findings are summarized as:

- The public is generally pleased with current snow removal activities; 87 percent believe that the highways are kept in satisfactory condition. Of these, 14 percent felt that there is not enough plowing.

- Forty-nine percent believed that it would hurt if levels of service were lowered. Nineteen percent believed a few inches [centimeters] of snow left on the highways would be all right.

- Overall, 26 percent believe that there would be no effect if levels of service were reduced (if not too much).

- Only 6 percent believed that it would help if levels of service were reduced.*

The overall impression was that any significant reduction in levels of service will be met with resistance by the public.

Surveys of this type indicate an awareness on the part of the public of snow and ice activities and generally support present levels of effort expended [26].

---

*These were primarily motel owners who though that their business would increase because people would be snowed in.

Through interviews, it was found that residents have difficulty in realistically evaluating the overall snow removal program. Concerning all interviewees, 32 percent of the respondents gave no response concerning the adequacy of the municipal snow removal program [26].

Ramsey County, St. Paul, Minnesota, reported in 1974, [27] even though people call regarding improved service during snow storms, they generally do not understand that the quality of service is directly related to manpower, equipment and materials (including fuel) expended. For the most part, the public is understanding and realizes that fuel and manpower supply is not endless. People are willing to settle for less in the way of traveling convenience as long as they know the condition is only temporary. And "temporary" in this case is a matter of hours until the road conditions will improve.

Other forms of public opinion and attitude have surfaced in recent years. Legislation concerning the use of deicing chemicals and the corresponding environmental effects have ensued. In 1971 the Minnesota Legislation limited the use of deicing salt or other chemicals to "such places as upon hills, at intersections or upon high speed arterial roadways where vehicle traction is particularly critical," and only if road authorities feel snow and ice removal cannot be accomplished by other means within a reasonable time. Anyone using more than one ton of deicing materials in any calendar year is required to report how much was used to the Department of Public Health. Massachusetts was the only state to pass a regulatory bill since the 1971 Minnesota bill.

> *The Massachusetts bill recognizes that salt storage is the main problem. It says: "No person shall store sodium chloride, calcium chloride or chemically-treated abrasives or other chemicals used for the removal of snow or ice on roads in such a manner or place as to subject a water supply or groundwater supply to the risk of contamination. The Department of Public Health ... in consultation with the Department of Public Works may issue regulations as to place or manner of storage of such chemicals and may, by specific order, in a particular case regulate the place where such chemicals may be used for such purpose"* [28].

Pennsylvania and Oklahoma killed attempts to pass anti-salt bills.

The latest state to consider deicing salt control legislation is Wisconsin. It was defeated. The bill would have required highway crews to restrict use of salt to extreme highway conditions and only on those parts of a road where traction is especially critical. A fiscal note by the State Department of Transportation, introduced into the debate, estimated it would have cost more than $2 million a year to institute a no-salt policy on state highways. Defeat of the Wisconsin Senate bill came during one of the major snowstorms of the winter.

In the city of Madison, Wisconsin, in 1975 buoyed by apparently widespread citizen support, the City Council has given the go-ahead for a street salt reduction program throughout the whole city for the next three winters.

The reduced salt usage in residential areas is aimed at minimizing damage to the environment, particularly the lakes, from salt runoff, and also at cutting down on corrosion of automobiles caused by salt.

Salt is to be reduced by twenty percent this winter, with an eventual goal of a 50 percent dropoff by 1977-78 [29].

Both forms of public opinion arising from legislation and individual reactions to winter "drivable conditions" indicate an awareness on the public's part to snow and ice maintenance. However, caution should be exercised when setting levels of service based solely on citizen outcry. As observed from the questionnaires, a large percentage of the public are unaware of the effort required to maintain snow and ice free road conditions but are perceptive of the costs and problems associated with maintaining levels too high.

Sovereign Immunity

The maintenance function as it relates to highways has gradually become a subject of concern to the law and its practitioners. The erosion of the doctrine of sovereign immunity has helped to create an awareness of maintenance, with special attention given to the liability aspects [23].

In the case of McCullin Vs State, Department of Highways, 216 So. 2d 832 (la., 1968), the plaintiff was injured in an accident arising out of an alleged defect in a graveled road [23]. There was adequate testimony in the case from which the court could find regular maintenance and inspection. In addressing itself to this point, the court said:

> *The State of Louisiana owes to the public a duty to maintain its highways so they will be in a reasonably safe condition for the traveling public at all times. This duty encompases an obligation to have an efficient and continuous system of inspection of the highways and bridges. The Highway Department, however, is not required to maintain a perfect condition of inspection but its officers and employees are required to use ordinary and reasonable care in order to insure that the highways and bridges will be in a reasonably safe condition. (cite omitted).*

This duty to use ordinary care referred to by the court has been interpreted to involve an anticipation of defects which could result naturally from the use or climatic conditions and in the absence of anticipation thereof, liability may well ensure [23].

The case of Shaw Vs State, 290 N.Y.S. 2d 602 (N.Y. Ct. Cl., 1968), involved a wrongful death claim which resulted from an accident in which the occupant of a stranded car was killed when he stood conversing with the occupants of another vehicle which had stopped partially on and partially off the highway and which was struck by an oncoming vehicle. The plaintiff claimed negligence in the maintenance of the highway. There was testimony that there was snow on the road and that it was cold, but it had not snowed on the day of the accident. A gusty wind was blowing, and conditions were similar throughout the immediate area [23].

In holding that the state was not negligent, the court said:

> *... In the exercise of reasonable care and maintenance the State is not required to go to the limits of human ingenuity to accomplish safety of the highway. (cite omitted) The brief period of time during which the snow condition due to weather and gusty wind conditions had existed was not sufficient to constitute constructive notice to the State which imposed negligence on it for failure to sand. Mere presence of snow or ice on the highway in the wintertime and the mere fact that a vehicle skidded thereon do not constitute negligence on the part of the State. (cite omitted) Under the weather conditions prevailing that afternoon and early evening there was an element of hazard which was obvious and reliance could not be placed on the presumption of the safety of the highway. (cite omitted) The cause of the accident cannot be attributed to the State under the facts herein ...*

It has further been held that the discharge of the duty in accordance with generally accepted engineering standards and practices meets the test of reasonable care [23].

In instituting maintenance "standards" it is necessary to keep in mind that in the absence of specific guidelines the courts operate under the doctine of reasonability. But where specific guidelines (standards, policy and procedures, etc.) are in existence the court will follow them [23].

Procedures and Policy - Level of Service

The level of service provided by a highway agency in snow and ice control is the key to estimating the extent of user benefits, user costs and maintenance costs. Here, level of service is used to represent a "goal" to be achieved in the snow and ice removal operation. The goal may be thought of as bare pavement as soon as possible, clear road within eight hours after the storm, road closures....

Traditionally levels of service have been determined primarily from the traffic volume and highway type. Table 4 shows what criteria is being used to set levels of snow and ice control in the snow-belt states.

TABLE 4: FACTORS WEIGHED IN DETERMINING LEVEL OF SERVICE AND/OR PRIORITY

STATE	FACTORS WEIGHED IN DETERMINING THE LEVEL OF SERVICE AND/OR PRIORITY			WHO CAN ALTER THE LEVELS SET?
	ADT	HWY TYPE	OTHER	
Arizona	X	X		Foreman with district coordination
California	X		- Conseuqence of not providing appropriate level of service - Public interest and concern - Safety - Potential economic impact	District director working with head quarters maintenance
Connecticut		X		Foreman within set guidelines
Delaware			Bare pavement maintenance	
Idaho	X	X	School bus routes	District maintenance superintendent and foreman
Illinois	X	X		
Indiana			Commission Snow & Ice control policy	
Iowa		X		Foreman within guides
Kansas		X		District superintendent and foreman
Kentucky	X	X		Director of maintenance
Maine		X	Bare Pavement - Priority set by area division	
Maryland			- Emergency routes - District Engineer designates	
Massachusetts			Set by Law	
Michigan	X		- Overtime considerations - Weekend Recreational	
Minnesota	X			
Missouri	X	X		
Montana	X	X	School bus routes	Section supervisor and worker
Nebraska	X			
Nevada			- Overtime considerations - Snow plan prepared by district	Supervisor in charge
New Hampshire	X	X	- Design speed - Grade	Patrol foreman
New Jersey			Set by line supervision	Foreman
New York	X	X	Average speeds	
North Carolina	X			Maintenance supervisor
North Dakota	X	X		District Office
Ohio		X		Superintendent and worker
Oklahoma	X	X		
Pennsylvania	X	X	Access	
South Dakota	X			Supervisor
Tennessee	X	X		District engineer and foreman
Texas	X	X		Local
Utah	X	X		District maintenance engineer & foreman
Vermont			Set by Law	
Virginia	X	X	Snow emergency routes	
Washington	X	X		
West Viriginia	X	X	School bus routes	District Headquarters
Wisconsin	X			District supervisory personnel
Wyoming	X	X	- School bus routes - Emergency services	District maintenance engineer and foreman

The environmental protection agency [30] says,

> *...priorities for level of service should be based on traffic volumes because it reflects the degree of difficulty in snow and ice control, the speed of vehicles using the roads, and th skill and familiarity of the highway users traveling on these roads. Volume of traffic also reflects the number of people that will be inconvenienced by deteriorating road coditions. Often, level of service priorities are established (quite validly) by experience or tradition.*

From Table 4 it is noted the widewpread variability between states on determining the level of service and how to achieve that goal. Nowhere was the level of service determined or justified through an economic comparison of road user savings and the cost of maintenance, except by subjective estimates from the magnitude of the traffic volume. Arbitrarily setting levels of service appears to be what many states are doing. It is simple and direct. Also, it is not significantly different from the way many departments now determine what they will do [31]. But this method has its shortcomings. There are different factors that influence what level of service will be provided and over

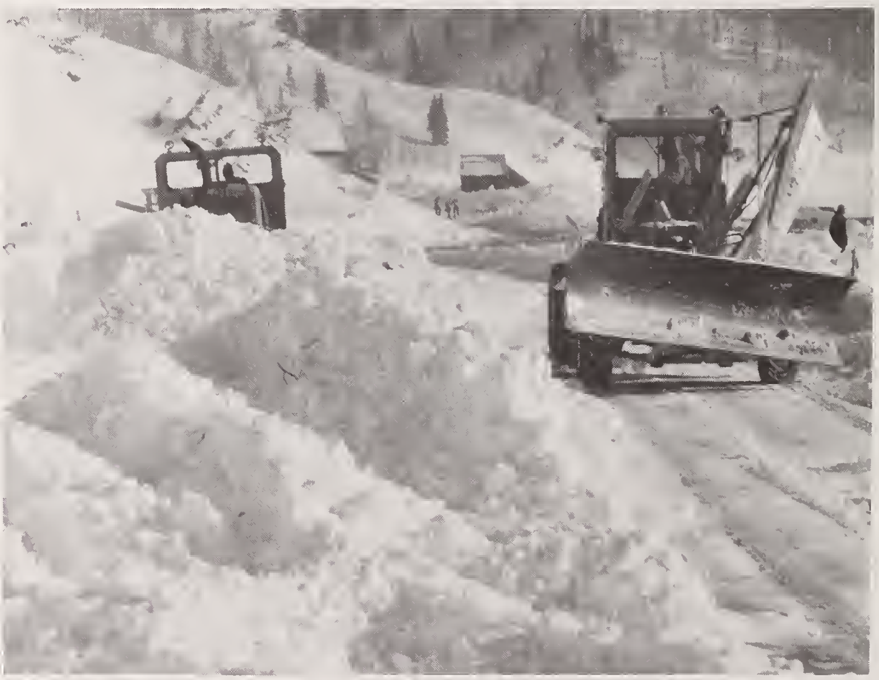


FIGURE 31 ROAD TO ALTA UTAH - ONE OF UTAH'S MOST DIFFICULT SNOW REMOVAL AREAS (Courtesy Utah Department of Transportation)

reaction may occur when all factors are not considered. For example, political pressures may result in levels being higher than warranted when comparing total needs of other segments. Developers build a ski resort, apply pressure to upgrade the road and then demand it be kept clear enough that all people or automotive machines can get there without too much inconvenience. In arbitrarily setting levels of service, too much importance may be placed on one factor [31].

If one considers that the level of service assigned should be consistent with needs that caused the road to be built originally, then it follows that arbitrarily setting levels without considering these needs may result in providing the wrong level. Actions taken to change levels of service to reduce fuel consumption and costs may actually cause increases [31]. Reduced costs to the department may be transferred costs to the public. For example, increased costs that trucking companies experience because of closed roads or increased fuel consumption will ultimately result in higher freight fees and in turn be passed on to the consumer. From economics we know that fixed costs become variable costs with time, thus rate increases are realistic to expect. Also, lost work time is a real cost -- to the employee as wages and to the general public through reduced productivity. Finally, if traffic accidents result from a change in levels of service inappropriately, judgements may be awarded against the department [31].

California, using a cumulative need factor plotted against need factor ranges as shown in Figure 32, determined break points for setting the levels of service. The cumulative needs were arrived at through a modified delphi analysis and represents the factors and their relative weights shown in Table 5.

The levels of service established, based on the criteria in Table 4 and the level of effort to accomplish this are summarized in the Appendix, Table 31 (page 194).

Levels of service or quality standards for maintenance operations have been developed to promote state wide uniformity in maintaining various aspects of the highway system. Usually the levels of service are interpreted as Highway Department policy for maintenance operations, However, from Table 4, several states allow or expect the area maintenance engineer or maintenance foreman to exercise his judgment to cover those situations that warrant more or less effort than dictated by the standard policy. This probably should be the case to allow for variations in climate, terrain or highway characteristics from one section to another, but it also weakens the actual uniformity of service provided between sections. Therefore, one of the primary uses of the level of service policy has been to a vehicle for establishing budget allocations and equipment needs to the various maintenance districts to combat snow and ice with.

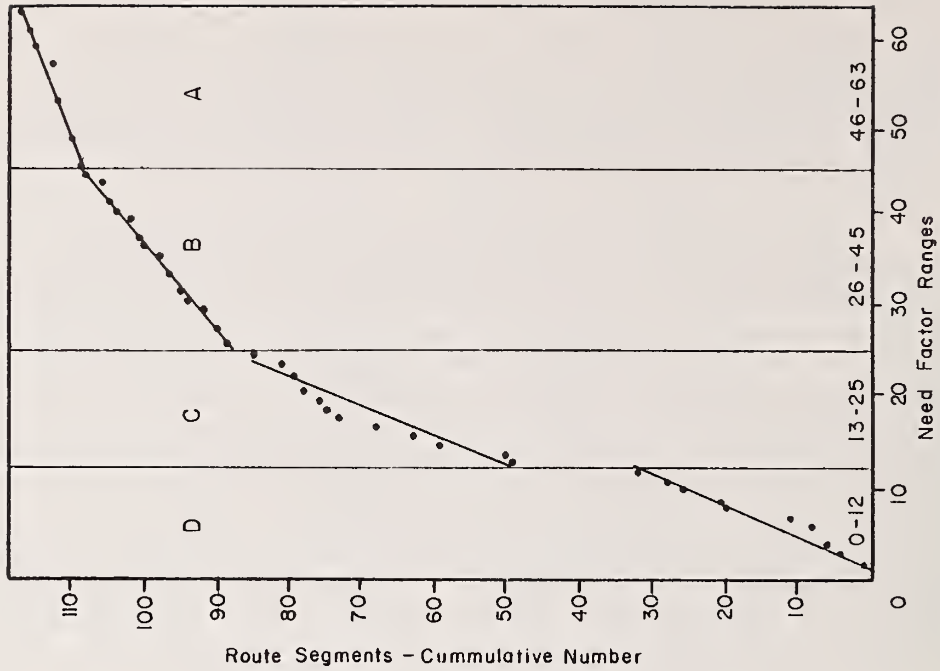


FIGURE 32 DISTRIBUTION OF NEED FACTORS RELATED TO ROAD CLASSES (25)

TABLE 5: CUMULATIVE NEED FACTORS AND THEIR RELATIVE WEIGHTS [199]

ROUTE	10 ADT	15 POLITICAL PRESSURE	12 ECONOMIC IMPACT	10 HWY USE	5 ACC PROB	10 EMERG VALUE	5 POP DENSITY	TOTAL
02-SHA 515-I5	11,000 17,500 10	15	8	10	1	10	5	59
03-ED-50	24,000 32,600 10	15	10	8	5	7	4	59
03-PLA-28	4,000 6,800 6	9	4	6	3	5	4	37
03-ED NEV 1-80	11,000 21,000 10	15	10	10	1	10	5	61
03-PLA-89	6,400 9,000 8	11	4	6	3	6	3	41
9-NMO-203	8,600 10,400 9	12	8	4	3	4	4	44
03-PLA-267	3,000 5,000 5	7	4	6	4	4	2	32
02-SHA-299	7,500 5,000 6	12	7	6	3	4	4	42
10-TUO-108	5	11	6	6	3	4	3	38

Budgeting

The methods of projecting money needs to establish a budget for snow and ice control vary. The most common budget source is through legislative action which considers a budget request and then issues a budget for the maintenance activity. A severe winter which might necessitate a larger budget than that allocated by the legislature would have to come from a general fund or be subsidized by the legislature. Some states essentially allow an open ended budget for snow and ice control, and the gasoline tax may be temporarily regulated to reimburese the costs for snow control in an exceptional winter. This, in effect, leaves the budget virtually unlimited for this acitivity. To accommodate for fluxuating winters in terms of dollars required to maintain a set snow plan, some states operate on a revolving or progressive budget. That is, a budget is such that it must be balanced on a sliding three or five year basis, rather than every year. If the dollar demand is high one year and is more than that year's budget estimate, then it may be made up the following year if a sub-severe winter occurs when the snow removal expenses are lower than those estimated. States who must work within the budget established for each year can not allow variance for over expenditures. Some allow expenditures to go into the red and be replenished by legislative action at a later date and some may not operate when expenditures dip below that set aside for the year.

Ohio has developed a linear equation for estimating snow removal costs for the state and uses this equation to allocate the budget between districts for snow and ice control. This development began with the collection of data relating to snow and ice control from approximately 4800 kilometers (3000 miles) of Ohio highways. Four items, or influence areas were used in the method for measuring the quality of maintenance, [34] and these are:

- The physical integrity of the elements of the highway,
- The safety of the facility for the user,
- The rideability of the pavement, and
- The aesthetics of the highway.

Ohio found ice and snow removal provides a service to the user. The elimination of the influence of ice and snow on the roads increases both the safety and the rideability of the road. The sooner the road conditions are brought back to normal the more effective the maintenance operation is considered to be. Therefore, the approach taken to evaluate the quality of ice and snow removal was to measure the length of time that a road was not in a normal condition. This was called the storm impact period and defined as the interval from the start of the storm to the time when the pavement becomes completely clear. The storm impact period is believed to be a function of the following variables: storm duration, snowfall, traffic, temperature, daylight, wind velocity, and time interval between start of storm and initiation of maintenance operation on the road.

Through multiple linear regression analysis, these variables were generated to establish the need or budget to be allocated for snow and ice control. The variable, ice storms was found to have the most significant effect on budget needs, but since this data has not been recorded by weather stations in the past, this variable had to be released from the final multiple regression model. The only drawback is that when approximately twenty years of climatic data is used for input to predict the upcoming years snow removal needs, the only variable that varies from location to location is the Average Daily Traffic (ADT). Consequently, two interstate highways side by side, one with 80,000 vehicles per day and one with 100,000 vehicles a day would receive a 20% difference in budget allocations to combat the snow and ice. However, Ohio has found this method to work satisfactory for establishing budget needs and allocations of money for snow and ice control.

The question, "If you budget for snow and ice control, how is the budget established?" was asked of the snow belt states by questionnaire, and the responses indicated that: The most common form of budget allocations is based on history or previous years experience. The total budgeted amount for snow and ice control as it relates to total maintenance dollars in snow states was also asked, and their values are summarized in Tables 6 and 7.

A snow and ice control budget is related directly to the severity of the winter. From an operational standpoint, we can staff to accommodate a certain rate of all; but from a budgetary standpoint, it is more important to think in terms of total accumulation and duration. By comparing staffing levels (as set by the snow plan) with the total number of hours of expected plowing, a budget can be developed in terms of labor. Material and equipmement can then be calculated by applying applicable standards.

The budget must be based on an "average" winter. Because severity varies considerably from winter to winter, it should not be expected that the budget predicted will always be close to actual. But assuming a normal probability distribution, using the average winter is most logical from a planning standpoint.

Productivity

Productivity as it relates to industry where it is monitored based on number of units built per time, etc., becomes a valuable tool in decision making to increase profits. Productivity, as applied to highway maintenance, particularly snow and ice control, is slightly more ambiguous. Guardrail repair may be evaluated on an average time schedule, but snow removal is not so easily quantified. Time is an indispensable element for evaluation of productivity. If it is geared such that the desired job, (removal of snow and ice as the goal) without specifying the time, no work would be required. Given enough time, nature will remove all winter traces from the highway in due course, thus the desired productivity will have been achieved.

TABLE 6: MAINTENANCE BUDGET TOTAL AND PERCENT SPENT FOR SNOW AND ICE REMOVAL

STATE	1971 to 1972			1972 to 1973			1973 to 1974			1973	1973	1974 to 1975		
	Total Budget*	% For Snow	Amt. For Snow*	Total Budget*	% For Snow	Amt. For Snow*	Total Budget*	% For Snow	Amt. For Snow*	Est. Lane Miles	Amt. for ea Lane Mile	Total Budget*	% For Snow	Amt. For Snow*
Arizona	16,930.00	4.0	677.20	15,800.00	12.0	1,896.00	17,317.50	4.0	692.70	15,302	45.27	18,881.50	5.0	944.08
California	98,008.90	9.0	8,820.80	113,385.90	9.0	10,204.73	129,868.80	9.0	11,688.19	45,274	258.17	140,275.60	8.0	11,222.05
Colorado (for 1973)								30.6	8,372.58	22,154	377.93			
Connecticut				29,403.05	23.0	6,762.70	30,428.19	25.0	7,607.05	4,325	1,758.86	29,440.31	23.0	6,771.27
Idaho**	8,555.79	22.1	1,891.98	8,866.34	22.7	2,013.61	10,093.10	16.1	1,625.27	11,714	138.76	10,917.35	17.4	1,902.26
Illinois	64,894.00	17.0	11,031.98	71,800.00	14.0	10,052.00	63,202.00	18.0	11,376.36	42,679	266.56	64,854.00	16.0	10,376.64
Indiana	45,799.01	8.9	4,076.11	47,379.48	9.4	4,453.67	49,460.74	10.4	5,143.92	28,399	181.13	56,888.52	9.6	5,461.30
Iowa	27,360.18	31.0	8,481.66	29,418.41	30.0	8,825.52	32,456.29	26.0	8,438.66	23,393	360.73	38,096.93	36.0	13,714.89
Kansas		18.0								24,065			17.0	
Kentucky	41,000.00	3.0	1,230.00	43,500.00	4.0	1,740.00	49,000.00	4.0	1,960.00	13,906	140.94	49,000.00	4.0	1,960.00
Maine	22,386.72	45.0	10,074.02	24,348.31	45.0	10,956.74	24,860.27	44.0	10,938.52			34,607.61	38.0	13,150.89
Maryland***	18,200.00	18.0	3,244.44	21,235.49	7.0	1,550.76	22,536.63	16.0	3,594.84	4,560	788.34	24,604.00	14.0	3,438.37
Michigan	36,683.92	31.4	11,518.75	40,017.62	31.6	12,645.57	42,496.05	32.6	13,853.71	26,258	527.60	46,994.43	31.5	14,803.25
Minnesota	36,439.00	26.6	9,691.00	38,770.00	21.9	8,482.00	39,545.00	24.6	9,722.00	29,547	329.04	48,377.00	34.5	16,670.00
Missouri	69,797.05	7.7	5,413.43	71,580.09	9.5	6,826.20	84,533.13	8.5	7,199.91	20,614	349.27	101,652.06	8.5	8,637.86
Montana	14,529.98	21.8	3,171.85	15,152.88	13.5	2,048.31	15,255.38	19.1	2,914.21	15,113	192.83	18,186.68	22.1	4,012.30
Nebraska	15,296.04	8.5	1,303.71	16,635.56	19.7	3,280.65	19,329.10	13.5	2,626.87	21,219	123.80	21,901.57	15.0	3,283.59
New Hampshire	13,511.03	49.0	6,620.41	13,467.74	43.0	5,791.13	14,645.91	35.8	5,243.23	4,768	1,099.67	17,282.01	39.2	6,774.55
New Jersey	16,140.40	12.8	2,065.97	18,213.85	5.2	947.12	17,701.14	21.7	3,841.15	7,411	518.30	19,989.89	7.2	1,439.27
New York	86,097.71	35.2	30,306.39	92,033.20	34.8	32,027.55	89,586.99	26.5	23,740.55	37,163	638.82	94,471.17	22.2	20,972.60
North Carolina	96,460.00			106,401.00			107,991.00			32,598		100,069.40	1.6	1,517.05
Ohio	73,650.00	23.4	17,234.10	84,475.00	18.5	15,627.88	92,685.00	21.6	20,019.96	48,161	415.69	102,870.49	23.1	23,763.08
Oklahoma				17,500.00	7.9	1,382.50	17,700.00	3.4	592.95	28,038	21.15	20,400.00	3.7	746.64
Pennsylvania	203,610.56	24.0	48,866.54	233,200.23	16.0	37,312.04	260,725.47	15.0	39,108.82	40,715	960.55	325,008.70	15.0	48,751.31
South Dakota	8,919.10	12.0	1,070.29	9,306.70	12.0	1,116.80	9,795.90	10.0	9,979.59	20,012	48.95	13,511.30	18.0	2,432.03
Tennessee	24,088.16	8.0	1,927.05	29,726.32	5.0	1,486.32	32,501.68	4.0	1,300.07	24,399	53.28	32,391.59	3.0	971.75
Texas	99,266.00	2.6	2,580.92	108,869.00	7.5	8,165.18	122,263.00	2.2	2,689.79	160,746	16.73	137,867.08	2.0	2,757.34
Utah	9,466.40	22.0	2,082.61	11,006.00	23.0	2,531.28	12,472.50	21.0	2,619.23	13,233	197.93	13,370.00	28.0	3,743.60
Vermont	9,546.52	45.0	4,295.94	9,941.40	43.0	4,274.80	10,216.40	40.9	4,178.51	6,183	675.81	9,612.74	49.4	4,748.70
Virginia	43,303.73	13.8	5,975.91	44,472.37	10.8	4,803.02	50,308.00	15.3	7,697.12	27,859	276.29	55,810.09	14.2	7,925.03
West Virginia	77,202.38	8.7	6,725.75	72,664.65	7.9	5,764.97	65,693.10	7.6	4,982.71	11,702	425.52	68,148.14	11.95	8,147.34
Wyoming**	7,833.70	34.0	2,663.46	8,555.94	26.0	2,224.55	10,621.46	26.0	2,761.58	14,805	186.53	12,185.64	25.0	3,046.41

* In Thousands of Dollars

** Calendar Year 1971, 1972, 1973, 1974

*** Fiscal Year 1972, 1973, 1974, 1975

TABLE 7: 1975 ESTIMATES OF SNOW AND ICE BUDGET ITEMIZATIONS FOR LABOR, EQUIPMENT, MATERIAL AND ADMINISTRATION

STATE	See NOTE	PERCENT OF SNOW AND ICE BUDGET FOR				STATE	See NOTE	PERCENT OF SNOW AND ICE BUDGET FOR			
		LABOR	EQUIP	MAT'L	ADMIN			LABOR	EQUIP	MAT'L	ADMIN
Arizona		49	41	8	2	Nebraska		44	40	11	5
California	a	44	36	16	13	New Hampshire	g	34	28	37	
Colorado	b					New Jersey	h		44	55	
Connecticut	c	50	16	34		New York		45	22	30	3
Idaho		39	43	18		North Carolina	i	35	20	45	
Illinois		34	26	25	15	Ohio	j	28	17	55	
Indiana	b					Oklahoma	b				
Iowa		55	22	23		Pennsylvania	k	39	33	28	
Kansas	d	29	47	12	12	South Dakota	l	34	49	17	
Kentucky	b					Tennessee		37	44	19	
Maine		34	25	25	16	Texas		53	32	10	5
Maryland	b					Utah		36	39	25	
Michigan		14	19	67		Vermont	m	34	25	41	
Minnesota		42	31	12	15						
	e	34	38	13	15	Virginia	n	46	12	42	
Missouri	f	56	16	21		West Virginia		35	13	45	7
Montana		50	33	12	5	Wyoming		42	43	12	3

a- 4% for other items; administration including in the labor, equipment, material, and other
b- information not readily available
c- the 16% for equipment is for rentals of trucks to supplement state owned equipment
d- snow and ice constitutes 17% of total 1974-75 maintenance budget with snow and ice manpower at 5%, equipment at 8%, material at 2%, and administration at 2% of the total maintenance budget
e- top number = estimates for twin city metro area - bottom number = estimates for areas outside metro area
f- administration costs not isolated - remaining costs are tools, supplies, and miscellaneous
g- 1% for miscellaneous travel expense - Administration is charged to separate engineering account
h- weather service clothing and safety = 1% - department equipment and manpower is used from the road maintenance budget
i- for snow and ice expenditures 1974-75
j- percents are of total direct cost of snow and ice budget - indirect cost is 68% of total direct cost of snow and ice budget
k- equipment includes 16.2% for rentals of private equipment and 16.3% for department owned equipment
l- these percentages based on expenditures for 1974-75 = Administration is included in overall maintenance budget
m- based on 4 year average
n- administration included in the labor percentage

There is a profit factor in winter maintenance, but the question of how to measure this profitability as a function of maintenance productivity remains. Pennsylvania [35] proposed that in place of profits, the level of service be measured that is provided the public as in Figure 33.

$\frac{\text{Costs}}{\text{Dollars}}$	$\frac{\text{Benefits}}{\text{Effects of Service}}$

FIGURE 33: MODEL IN WHICH BENEFITS ARE MEASURED VIA THE EFFECTS OF SERVICE (35)

The alternative form is some quantitative or accounting compilation of the service activity itself. The effects on service would include volume of traffic, number of accidents, etc., while number of miles of highway plowed, tons of antiskid material spread, actual time required to service all roads, etc., are measures of the service activity itself. Figure 33 denotes the model in which benefits are measured via the effects of service: Figure 34 denotes the model in which benefits are measured according to some quantitative accounting of the actual service activity:

$\frac{\text{Costs}}{\text{Dollars}}$	$\frac{\text{Benefits}}{\text{Service Units}}$

FIGURE 34: MODEL IN WHICH BENEFITS ARE MEASURED ACCORDING TO SOME QUANTITATIVE ACCOUNTING OF THE ACTUAL SERVICE ACTIVITY (35)

It was decided to concentrate on the strategy indicated by Figure 34 [35]. "Cost Effectiveness Studies of Antiskid and Deicing Programs in Pennsylvania" contains a summary of the results of the research that was published in separate interim reports which include models of optimum policies for purchasing of materials, management controls, cost analysis and evaluation, and a model for the dispatching and routing of equipment. Each of these models is concerned with cost of maintenance versus level of service; the procedure has been to develop models for maximizing levels of service for a fixed budget, as in the case of the routing model, minimizing cost for a fixed level of service, as in the cost analysis and regression models.

In NCHRP #42, [36] the states of Texas, New York, California, Florida and Ohio were used to evaluate units of maintenance productivity. These observations included many different successful methods which are employed by maintenance crews and the versatility and ingenuity of those planning maintenance work. Most of the procedures were well planned, within the limitations which affected the planning. The studies view to improving or optimizing the procedures pinpointed the fact that for a maintenance operation there is seldom a single optimized procedure that is fully applicable at a great number of locations. Limitations are related to the design and operational characteristics of the highway, the types of equipment available and a variety of other local factors [36].

For the development of a quantitative measure of Interstate maintenance requirements, expressed in terms of the labor, equipment and material units, it was necessary to explore the relationship between the work load being generated by each test section and the various physical, environmental and traffic factors having a potential influence on the work load.

In some instances, work load can be measured in terms of the amount of work needed to correct a roadway deficiency (e.g., yards of patching, lineal feet of joint sealing, acres of mowing). In other instances, the appropriate measure will be the labor, equipment and material units needed to remedy a deficient condition, such as with snow and ice control.

This suggests that the best measure of work load is the labor, equipment and material investment rather than a quantitative measure of the work. An evaluation of work load in labor, equipment and material units more readily accommodates the widely divergent job sizes and procedures associated with each of the maintenance activities [36]. Of course, built into the reported labor, equipment and material expenditures are potential crew inefficiencies, low production activities, and variations in the adequacy of accomplishment.

For the states evaluated, a regression model was established to estimate the costs associated with snow and ice control.

The data were adjusted to produce comparable units of labor, equipment and material for the various test sections; i.e., the units reflect values of equal magnitude.

The adjusted snow and ice control expenditures for the centerline-mile equivalent of four lane-miles were used as the dependent variable in the evaluation of snow and ice control requirements. The following independent variables, regressed against the dependent expenditures, resulted in variables 3, 4, 5, and 8 being selected for the final regression model:

1. Average annual precipitation.

2. Precipitation from November-April.
[3.] Snowfall, in inches.
[4.] Days of snowfall.
[5.] Days of snow cover.
6. Average annual temperature.
7. Average temperature (November-April).
[8.] Number of days when maximum temperature is below 0°C (32°F).
9. Number of days when minimum temperature is below 0°C (32°F).
10. Number of days when minimum temperature is below -18°C (0°F).
11. Urban and rural location.
12. Average daily traffic volume.
13. Average mean maximum temperature.
14. Average mean minimum temperature.
15. Terrain factor.

The multiple correlation value was quite good (0.975) and was the best of all the correlation values derived from the various models of maintenance requirements. The range of expenditures used for the dependent variables varied from 0 to 5,500 units per four lane-miles. The standard error of the estimate was 372 units, meaning that with 95 percent confidence the model predicts snow and ice removal requirements within 744 units per four lane-miles. An examination of the residual values (difference between given and predicted requirement units) revealed that all values but one fell within the confidence limits predicted. During the observation period, the one exception received only one-half the normal snowfall for that area. The fact that more expenditures were reported than the model would predict could have been the result of the fact that many built-in expenses were geared to handle twice the snowfall actually experienced.

The final regression model for snow and ice control was

$$Y_{18} = 14.8\ X_1 - 37.5\ X_2 + 24.3\ X_3 + 51.0\ X_4 \qquad (6)$$

in which

Y_{18} = Snow and ice control maintenance requirement units per four lane-miles of Interstate highway or its equivalent in interchanges or multilane pavements;

X_1 = Average annual snowfall, in inches;

X_2 = Number of days of snowfall (including days of "trace snowfall);

X_3 = Number of days with snow cover on the ground; and

X_4 = Number of days when maximum daily temperature was below 0° C (32°F).

An optimum job of snow removal must be based on many factors; traffic, weather, highway and many other variables difficult or impossible to control. For instance, the optimum snow removal plowing function may be once every five hours for one storm, at a frequency of half that again for another storm. Therefore, it seems appropriate, that after a level of service or goal has been established, the maintenance procedures to attain that goal with the resource constraints imposed such as equipment, fuel, manpower, materials, etc., should be used to their optimum efficiency, assuming the work or goal is achieved.

By this means the productivity (achieved level of service per storm) is improved through more efficient use of resources on hand to combat the storm. Not all procedures, materials, etc., will attain the same degree of efficient results from storm to storm or even between geographic areas, therefore a list of inefficient practices to be avoided is needed to facilitate the most productive job for a given situation.

To measure the productivity therefore requires a means to monitor the costs per storm to achieve the desired level of service. Only in this way will the highway administrator know if a change in resources such as equipment or materials is providing higher or lower costs to achieve the level of service, thus properly evaluating productivity.

Several states and documents relate evidence as to how and why unit costs can be monitored for maintenance activities [36]. Probably the most effective, that can isolate costs on a storm basis for manpower, equipment or materials is the use of some sort of management system.

Quality standards control how well the maintenance is done; quantity standards, when combined with the road and equipment inventory, define the work load required to meet the quality standards; productivity standards define how much manpower, eqiuipment, and materials are required to meet the work load. Managers must be aware that maintenance program budgeting requires a commitment of personnel and that there are several pitfalls that must be avoided. In general, program budgeting using performance standards can give maintenance managers a method of cost control not otherwise available to them.

P.J.F. Wingate of the Road Research Laboratory of Great Britain described the measures of productivity used in Great Britain and emphasized the use of performance standards in this process [37]. Some of the measures of productivity described by him were actual hours divided into standard hours, actual hours divided into wages, standard hours divided into wages, budget standard hours divided into standard hours work, and budget unit cost divided into actual unit cost. He concluded that the direct assessment of productivity is cumbersome to make and not very effective for controlling labor forces used in highway maintenance. However, the modified approach through performance standards to determine effective performance was considered indispensable for a proper control of labor utilization.

To instigate a management system responsive to the needs of snow and ice control, six basic components must be identified:

1. Criteria for maintenance levels
2. Maintenance levels
3. Work load
4. Resource requirements
5. Records and reports
6. Procedures for management planning, evaluation, and control.

The major elements of maintenance management are closely related and somewhat overlapping, and each must be given adequate emphasis if an engineering administrator expects to manage his program adequately, but if it is not carried out properly with adequate follow-up, the plan is worthless [38].

Contract Maintenance for Snow and Ice Control

Agencies responsible for snow and ice control have a considerable investment in equipment inventory and maintenance costs allocated for this purpose. Therefore it is essential that proper planning in terms of snow removal capacity or capability of a particular maintenance station be determined in conjunction with year round maintenance needs. Staffing and equipping for the maximum snow storm will yield an inefficient utilization of resources for the remainder of the season and being prepared for a storm that does not adequately represent the most probable storm will require over working the resources available to combat the storm or require lowering the level of service for intermittent periods of time, which may be beyond the maintenance managers control to avoid.

Tables 8 through 12 illustrate the variability between states that has heen recorded for extreme snow conditions [39]. These values are not representative of normal conditions and therefore should not be used for allocating resource capacity to maintenance stations.

Table 13 lists the most probable storm to be expected in a ten year period (10 year snowfall), this may be done on a yearly basis too. This number may be the most realistic in terms of evaluating snow removal needs or budgets, but certainly not peak snow storms.

Presently, contract maintenance or various forms of equipment rental is not uncommon, specifically in areas where constant demands are most readily projected. This includes bridge painting, surface repairs, painting of guardrail, and application of chemicals for vegetation control. Contract maintenance also is performed in one or more states for highway mowing, concrete pavement patching, bridge repairs, storage and shop building repairs, mudjacking of pavements, maintenance of traffic signals and lighting systems,

TABLE 8: GREATEST AMOUNT OF SNOWFALL, 24-HOUR PERIOD [39]

STATE	AMOUNT		DATE	LOCATION
	cm	Inches		
Arizona	78.7	31.0	Dec. 13, 1915	Flagstaff
California	152.4	60.0	Jan. 18-19, 1933	Giant Forest
Colorado	192.5	75.8	Apr. 14-15, 1921	Silver Lake
Idaho	66.0	26.0	Jan. 15, 1952	Arco
Montana	76.2	30.0	Oct. 29, 1951	Summit
Nevada	55.9	22.0	Jan. 12, 1952	University
New Mexico	76.2	30.0	Dec. 29, 1958	Sandia Crest
Oregon	71.1	28.0	Dec. 10, 1919	Bend
Utah	88.9	35.0	Feb. 9, 1953	Kanosh
Washington	132.1	52.0	Jan. 21, 1935	Winthrop
Wyoming	86.4	34.0	Jan. 28, 1933	Bechler River

TABLE 9: GREATEST AMOUNT OF SNOWFALL IN SINGLE STORM PERIOD [39]

STATE	AMOUNT		DATE	LOCATION
	cm	Inches		
Arizona	137.2	54.0	Dec. 29-31, 1915	Flagstaff
California	378.5	149.0	Jan. 11-17, 1952	Tahoe
Colorado	358.1	141.0	Mar. 23-30, 1899	Ruby
Idaho	132.1	52.0	Jan. 12-16, 1952	Sun Valley
Montana	116.8	46.0	Mar. 31-Apr.3, 1954	Summit
Nevada	111.8	44.0	Jan. 14-16, 1952	Marletto Lake
New Mexico	101.6	40.0	Dec. 14-16, 1959	Corona
Oregon	137.2	54.0	Nov. 17-20, 1921	The Dalles
Utah	162.6	64.0	Dec. 2-7, 1951	Alta
Washington	327.7	129.0	Feb. 24-26, 1910	Laconia
Wyoming	132.1	52.0	Jan. 15-19, 1937	Bechler River

TABLE 10: GREATEST AMOUNT OF SNOWFALL IN A CALENDAR MONTH [39]

STATE	AMOUNT		DATE	LOCATION
	cm	Inches		
Arizona	266.2	104.8	Jan. 1949	Flagstaff
California	990.6	390.0	Jan. 1911	Tamarack
Colorado	632.5	249.0	Mar. 1899	Ruby
Idaho	257.8	101.5	Jan. 1952	Island Park Dam
Montana	312.4	123.0	Jan. 1954	Summit
Nevada	271.8	107.0	Jan. 1950	Glenbrook
New Mexico	223.5	88.0	Jan. 1915	Anchor Mine
Oregon	650.2	256.0	Jan. 1933	Crater Lake
Utah	419.1	165.0	Mar. 1948	Alta
Washington	922.0	363.0	Jan. 1925	Paradise R.S.
Wyoming	478.8	188.5	Jan. 1933	Bechler River

TABLE 11: GREATEST AMOUNT OF SNOWFALL IN A SEASON [39]

STATE	AMOUNT		DATE	LOCATION
	cm	Inches		
Arizona	218.4	104.8	Feb. 8, 1949	Bright Angel
California	1,145.5	451	Mar. 10, 1911	Tamarack
Colorado	645.2	254	Mar. 30, 1899	Ruby
Idaho	462.3	182	Feb. 20, 1954	Mullan Pass
Montana	335.8	132	Apr. 3, 1954	Summit
Nevada	355.6	140	Mar. 19, 1952	Marletto Lake
New Mexico	182.9	72	Feb. 28, 1915	Anchor Mine
Orgeon	614.7	242	Mar. 18, 1927	Crater Lake
Utah	454.7	179	Apr. 5, 1958	Alta
Washington	932.2	367	Mar. 9, 1956	Paradise R.S.
Wyoming	243.8	96	Mar. 3, 1939	Bechler River

TABLE 12 GREATEST SNOW DEPTH OF RECORD [39]

STATE	AMOUNT		DATE	LOCATION
	cm	Inches		
Arizona	539.0	212.2	1940-41	Bright Angel
California	2,245.4	884.0	1906-07	Tamarack
Colorado	2,062.2	811.9	1936-37	Wolf Creek Pass
Idaho	903.0	355.5	1951-52	Island Park Dam
Montana	1,032.5	406.5	1958-59	Kings Hill
Nevada	782.3	308.0	1951-52	Marietto Lake
New Mexico	1,087.1	428.0	1914-15	Anchor Mine
Oregon	2,232.7	879.0	1932-33	Crater Lake
Utah	1,684.0	663.0	1951-52	Alta
Washington	2,540.8	1000.3	1955-56	Paradise R.S.
Wyoming	1,248.7	491.6	1932-33	Bechler River

TABLE 13: MOST PROBABLE STORM TO BE EXPECTED IN 10 YEAR PERIOD [39]

STATION	Average Annual Snow Fall		Projected 1 in 10 Yrs Snowfall		Average Liquid Precipitation Annual		Ratio Liquid-Snow Annual (1:10)	Liquid-Snow Ratio N.,O.,JF.M (1:10)	Record 24 Hour Maximum Snowfall		
	cent.	Inches	cent.	Inch	cent.	Inches			cent.	Inches	Mnth/YR.
Buffalo	271.3	106.8	488	192	82.02	32.29	3.3 to 1	1.3 to 1			
Rochester	209.0	82.3	373	147	80.62	31.74	3.8 to 1	1.5 to 1			
Hartford	103.1	40.6	185	73	102.82	40.48	10.0 to 1	4.7 to 1	41.9	16.5	3 / 21
Boston	108.0	42.5	193	76	98.45	38.76	9.1 to 1	4.1 to 1	48.3	19.0	3 / 49
Providence	84.3	33.2	150	59	100.66	39.63	12.0 to 1	5.4 to 1	38.1	15.0	1 / 43
Pittsburgh	98.3	38.7	175	69	94.01	37.01	9.2 to 1	3.6 to 1			
Harrisburg	84.3	33.2	150	59	91.47	36.01	10.3 to 1	4.0 to 1			
J.F.K.	77.0	30.3	137	54	109.78	43.22	14.2 to 1	5.8 to 1	65.5	25.8	12 / 47
Newark	76.7	30.2	124	49	126.90	49.96	16.5 to 1	5.6 to 1	66.0	26.0	12 / 47
Philadelphia	49.8	19.6	89	35	104.47	41.13	21.0 to 1	7.9 to 1	53.3	21.0	12 / 09
Baltimore	54.1	21.3	97	38	108.18	42.59	20.0 to 1	7.6 to 1	62.2	24.5	1 / 22
Dulles	51.1	20.1	91	36	96.60	38.03	18.9 to 1	6.9 to 1			
Washington	37.3	14.7	66	26	103.05	40.57	27.6 to 1	9.6 to 1	63.5	25.0	1 / 22
Richmond	30.5	12.0	53	21	126.95	49.98	41.6 to 1	13.0 to 1			

maintenance of pumping stations, and application of traffic lines and markings. The amount and extent of work varies from state to state.

The AASHTO Committee for Maintenance [32], is 1973 polled states on their use of performing maintenance activities by contract. The questions were structured to evaluate the type of maintenance projects conformable to contracts. They summarized that "the work schedule of maintenance forces is usually divided into major maintenance programs, normal maintenance operations and emergency operations." Therefore the major and normal type of maintenance operations are more readily adaptable to contracting out the work. Most maintenance work activities have suitable conditions for maintenance contracts where the work can be identified by some measurable unit, an estimate can be made for budgeting, the work can be described by plans and specifications and scheduled in advance.

Seven states reported contracting part of their snow and ice removal activities, which involved 83 contracts. Of the states utilizing maintenance for snow and ice control, equipment rental was reported in the range of $12.7 million, and $0.6 million for equipment rental on other maintenance operations which amounts to a total of approximately $13.3 million. Materials supplied by contract amounted to $25.6 million for snow and ice control and $72.9 million for other maintenance materials which amounts to an approximate total of $98.5 million or 25.6 percent of the total amount contracted.

In this survey, some of the reasons given for not contracting part or all of the snow and ice maintenance are:

-- Part of our contract work is of an emergency nature so many contractors are not prepared to go to work on short notice due to other schedules; therefore, the time element becomes a problem.

-- Lack of flexibility except in specialized operations. Cost is considerably more.

-- Time required for the preparation and processing of contract documents. Establishment of an inspection force to insure proper execution of the required work to be performed.

-- Material delivery by contract is often slow and has an adverse effect on our program.

-- Contractor does not complete the work on schedule.

-- On routine maintenance contracts the contractor response is not as quick as with State employees.

Contract maintenance for snow and ice control may or may not be appropriate for a given set of circumstances. One area where potential savings may be realized on an annual basis is to contract portions of snow and ice removal out to accommodate the peak demand from extreme snow storms on highways that require a minimum level of service or which cannot be closed for even short periods of time. This criteria coupled with a maintenance section with a large fluctuation in summer and winter maintenance demand should look seriously at implementing a form of maintenance work by contract.

Chain Laws

To reduce the direct maintenance cost of providing high levels of service on snow and ice convered highways, some agencies have adopted a "chain law" or modified form of regulation requiring traction aid devices on vehicles during inclement weather. It is believed from the safety aspect, a lower level of effort does not necessarily compromise safety to the roadway user.

Most agencies using some form of traction aid law has implemented it in the form of: chains will be required when, in the judgment of the responsible supervisor on duty, snow and ice conditions make it difficult for the average driver to control his vehicle.

Table 14 summarizes states with traction aid restrictions for certain poor weather conditions. These states have estimated that the cost to keep traffic flows comparable to their present efficiency should they not have traction aid regulations, would be considerably greater. States such as West Virginia maintain "chains must be on all equipment before going to plow snow." [40]

California has had very good experience with a chain law, and has

TABLE 14: STATES THAT CAN REQUIRE TRACTION AIDS

STATE	TO WHAT EXTENT CAN RESTRICTIONS BE MADE			RESPONSIBILITY FOR DETERMINING WHEN NECESSARY	RESPONSIBILITY FOR ENFORCING
	CHAINS ONLY	CHAINS OR SNOW TIRES	MOST AIDS		
Arizona			X	Highway Patrol & Highway Department	Highway Patrol
California	X	X	X	Highway Department	Highway Patrol
Colorado			X	Highway Department	Highway Patrol
Delaware			X	Municipalities	Local Police
Maine			X	Municipalities	Local Police
Maryland			X	Municipalities	Local Police
Missouri			X	Municipalities	Local Police
Montana			X	Not Available	Not Available
Nebraska			X	Municipalities	Local Police
Nevada			X	Highway Department	State or Local Police
Ohio			X	Municipalities	Local Police
Pennsylvania			X	Municipalities	Local Police
Utah			X	Highway Department	Highway Patrol
Virginia			X	Municipalities	Local Police
Washington			X	Highway Department	Highway Patrol
Wyoming	X			Highway Patrol & Highway Department	Highway Patrol

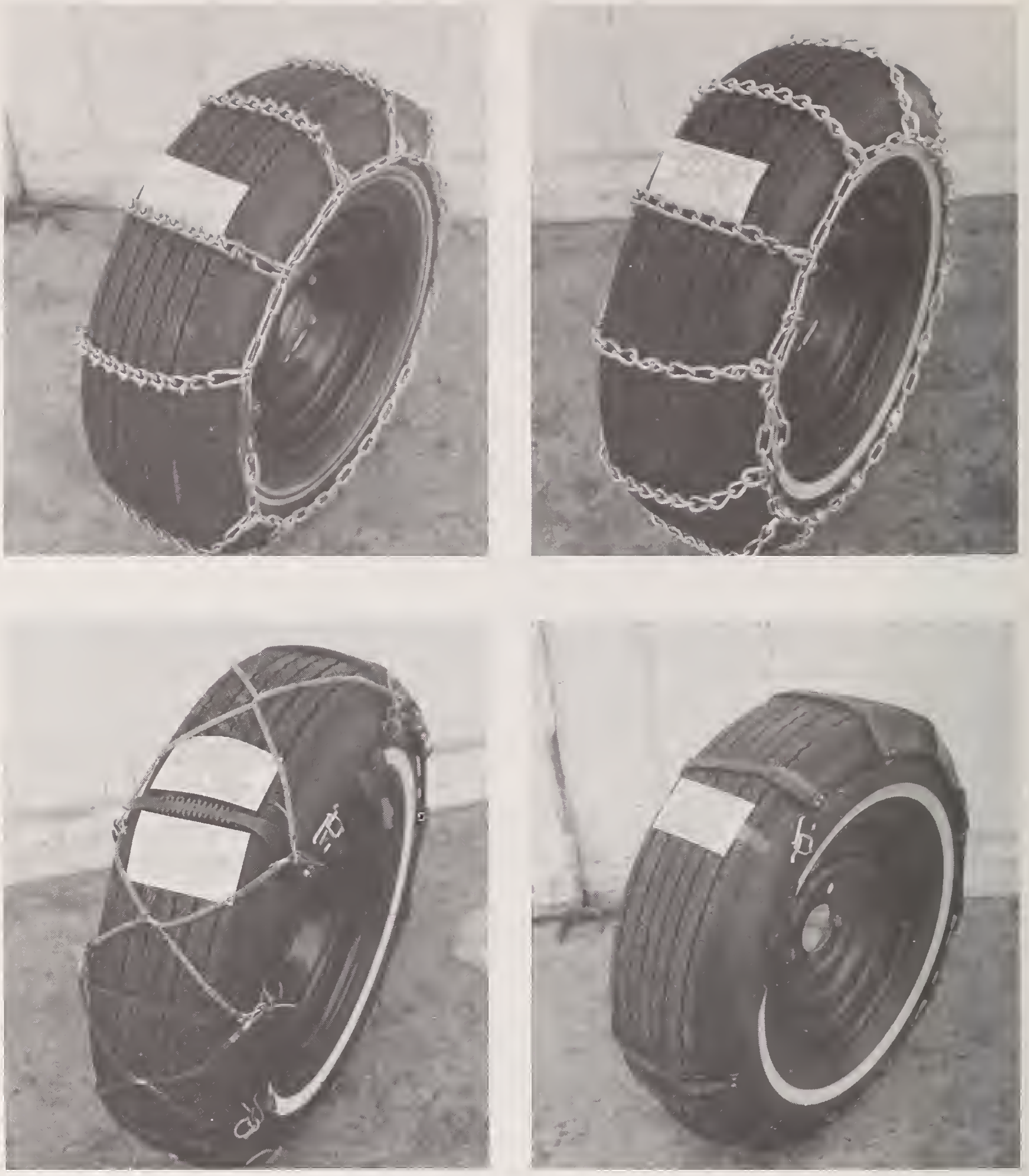
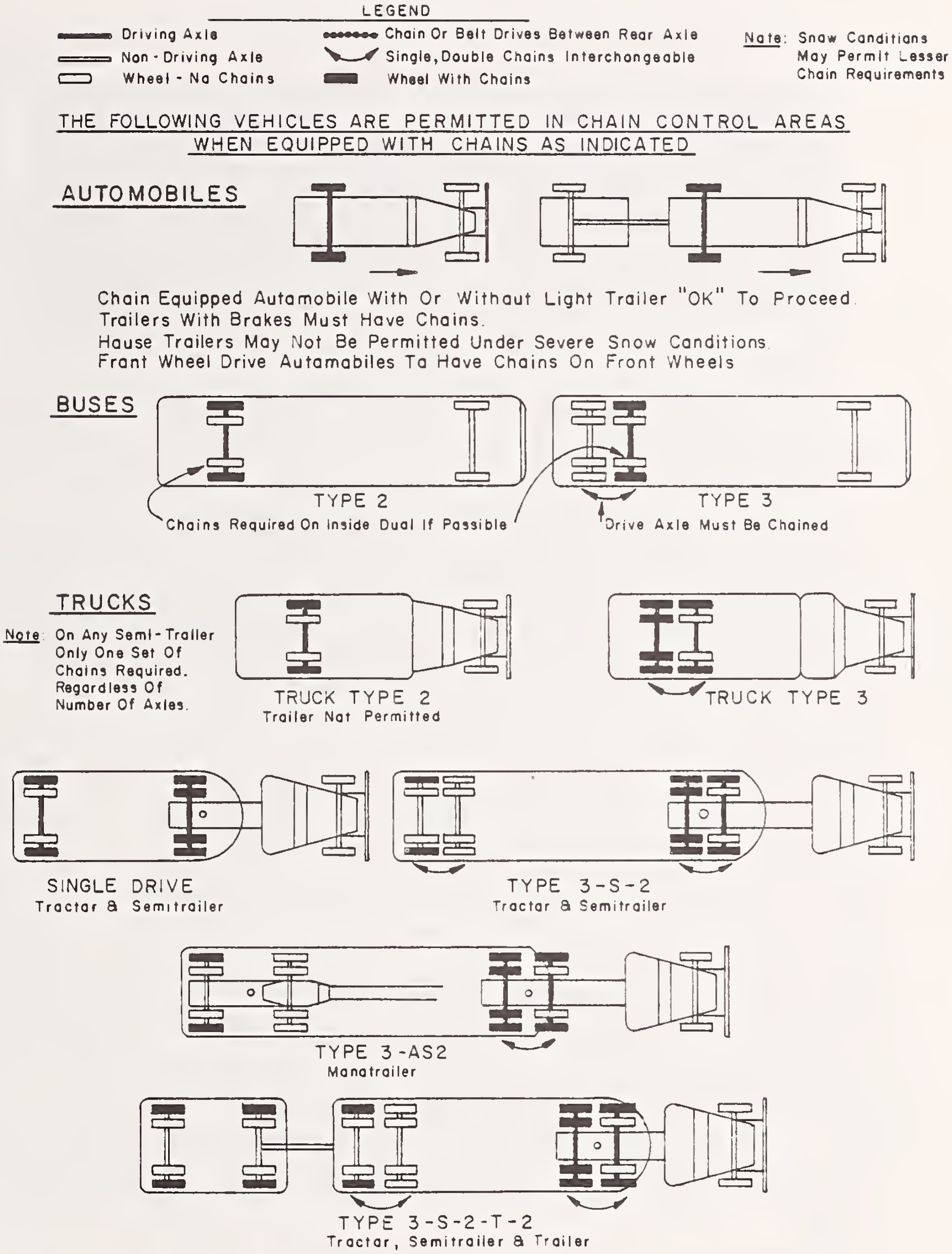


FIGURE 35: VARIOUS TYPES OF TRACTION AIDS (Courtsey of The National Safety Council)



THE FOLLOWING VEHICLES ARE PERMITTED IN CHAIN CONTROL AREAS WHEN EQUIPPED WITH CHAINS AS INDICATED

Chain Equipped Automobile With Or Without Light Trailer "OK" To Proceed.
Trailers With Brakes Must Have Chains.
House Trailers May Not Be Permitted Under Severe Snow Conditions.
Front Wheel Drive Automobiles To Have Chains On Front Wheels

Chains Required On Inside Dual If Possible

Drive Axle Must Be Chained

Note: On Any Semi-Trailer Only One Set Of Chains Required. Regardless Of Number Of Axles.

FIGURE 36 CALTRANS MAXIMUM CHAIN REQUIREMENTS

applied it in the following manner:

There are three conditions for which standard signing for snow control areas are necessary.

1. The first condition is when chains are required but autos and pickups with snow tires are excepted from using chains.

2. The second condition is when chains are required but vehicles with four wheel drive and snow tires on all four wheels are excepted from using chains.

3. The third condition is when chains are required with no exceptions.

The recommended way of signing these conditions is shown in Figure 37. (25 mph = approx. 40 kilometers per hour).

Colorado has a less strict traction aid requirement than California, and has summarized it as the department of highways shall also have authority to close any portion of a state highway to public travel, or to prohibit the use thereof unless motor vehicles using same are equipped with tire chains or snow tires having a tread of sufficient abrasive or skid resistant design or composition, and depth to provide adequate traction under existing driving conditions, during storms or when other dangerous driving conditions exist, or during construction or maintenance operations, whenever it considers such closing or restriction of use necessary for the protection and safety of the public. Such prohibition or restriction of use shall be effective when signs giving notice thereof are erected upon such portion of said highway and it shall be unlawful to proceed in violation of such notice. The Colorado state patrol shall cooperate with the department of highways in the enforcement of any such closing or restriction of use. "Tire chains", as used herein, are defined as metal chains which consist of two circular metal loops, one on each side of the tire, connected by not less than nine evenly spaced chains across the tire tread.

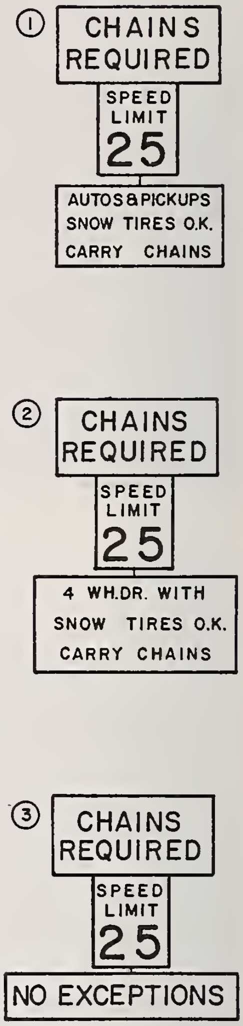


FIGURE 37 CALTRANS CHAIN CONTROL SIGNING (196)

Snow Fences

Snow fences, when properly installed, can be an effective aid in controlling the adverse effects from blowing and drifting snow.

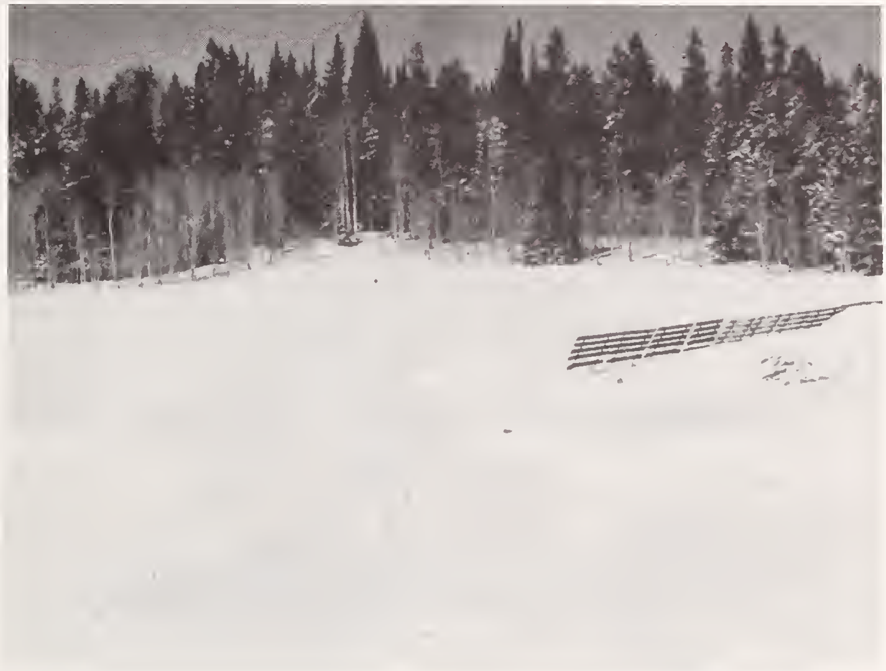


FIGURE 38: SNOW FENCE INSTALLATION IN THE UNITAH MOUNTAINS
(Courtesy Utah Department of Transportation)

Wyoming, with a severe potential for ground blizzards resulting from blowing snow, particularly along Interstate-80 in the southern portion of Wyoming, has evaluated and experimented with various snow fence geometrics. Dr. Ronald D. Tabler with the U.S. Forest Service and in conjunction with the Wyoming Highway Department [41] and [190] has worked with fences up to 3.65 m (12 feet) high and using a design wind velocity of 209 kilometers per hour (130 mph), designed a number of experimental fences. Short sections of each type of fence were constructed for observation and analysis.

Because of the stress placed in the literature on fence orientation with respect to the prevailing wind, a vertical "zig-zag' wood fence was laid out in a sawtooth pattern to attempt to accommodate varying wind directions.

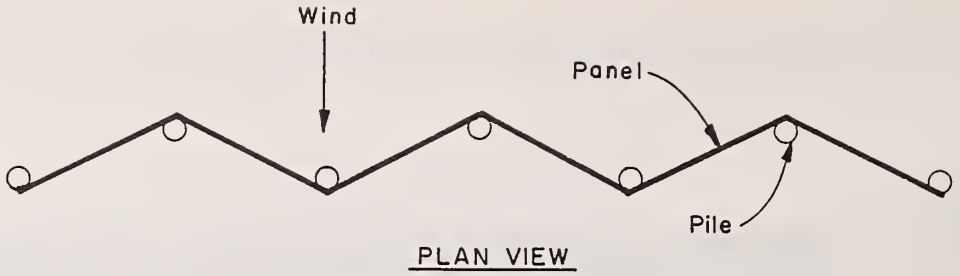


FIGURE 39 ZIG-ZAG SAWTOOTH SNOW FENCE PATTERN (41)

Inclined wood fences, modifications of the old Swedish designs, wit with cable and deadman anchors, were designed in 1.8, 2.4, 3.0, and 3.7 meter (6, 8, 10, and 12 feet) heights.

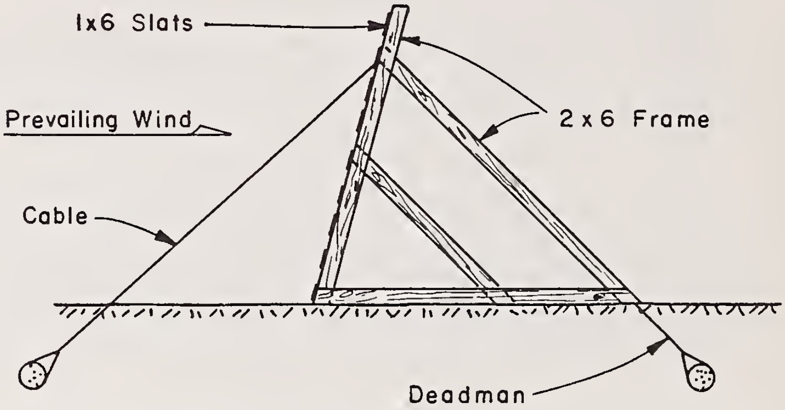


FIGURE 40 MODIFIED SWEDISH SNOW FENCE DESIGN WITH CABLE AND DEADMAN ANCHORS (41)

A third type, similar to the modified Swedish design, but using precast concrete supports and PVC slats, was also evaluated. The weight of the concrete eliminates the need for any anchorage system.

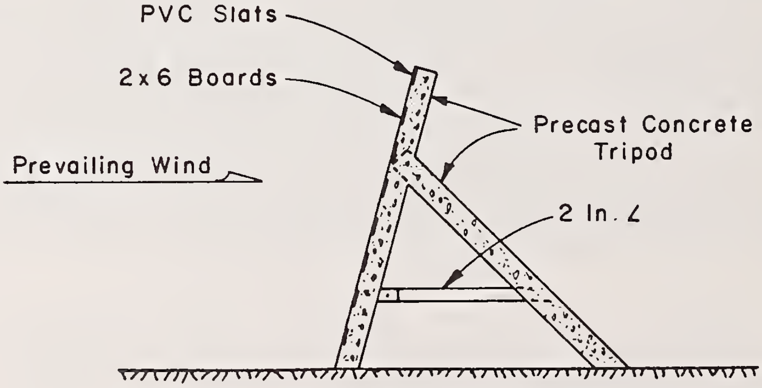


FIGURE 41 MODIFIED SWEDISH SNOW FENCE DESIGN USING PRECAST CONCRETE SUPPORTS AND PVC SLATS (41)

After observations of each type design, the conclusions were that the "zig-zag" fence was not really as effective for various wind directions as hoped. By comparison with the inclined design, it was only 40 percent as effective in trapping snow. The drift pattern indicated that the wind was funneled into the "V" portion of the fence increasing velocity and eroding the drift away from the fence.

The concrete fence failed at the welds, but the precast concrete tripod presented enough mass to prevent overturning without external anchors. With better welded joints, this design could be functional in selected areas due to appearance and ease of installation.

The inclined wood fence with redesigned anchors was finally chosen as the best design to use in Wyoming.

In 1971, a contract for the construction of approximately 18,440 lineal meters (60,500 feet) of snow fence was awarded for $480,000. This covered 56 kilometers (35 miles) of I-80 and consisted of wooden fence in heights of 1.8, 2.4, 3.0, and 3.7 meters (6, 8, 10, and 12 feet). The cost per meter was $17.22, $20.51, $24.61, and $26.84 (per foot $5.25, $6.25, $7.50, and $8.18), respectively.

The approach used by Dr. Tabler for the design of the snow fence sites was to:

1. Determine the mean annual snowfall for the area.
2. Determine the quantity of relocated snow with the use of a mathematical model.
3. Determine the quantity of snow storage behind the varying fence heights.
4. Determine the number of rows of fences required to trap the blowing snow.

Weather substation records were used to ascertain the mean annual snowfall and in determining an elevation factor using a regression analysis.

The quantity of relocated snow was expressed as:

$$q_b = \theta P R_c - q_1 - q_s$$

where:

q_b = quantity of relocated snow (cubic feet of water per foot of width).

θ = snow transfer coefficient or the ratio of the amount of snow that is relocated to that which falls as precipitation.

P = mean precipitation received over the contributing distance R_c. (ft.)

R_c = the contributing distance or the distance upwind of a snow fence which contributes snow particles to the snow drift. (ft.)

q_1 = total sublimation loss during transport over the distance R_c.

q_s = the natural storage of snow over the contributing distance R_c.

R_m = mean distance over which an average size snow particle must travel before completely sublimating (ft.).

The volume of snow which is stored behind a fence is a function of the fence height (H) as well as the density of the fence. (Density is the percentage of the total area of a fence which is of solid material). The length of an induced snow drift is also a function of the fence height. In level terrain, the maximum height of a drift formed is equal to the height of the fence. Since the fence to be erected was a new design not previously used by the Department, it was necessary to estimate the maximum cross-sectional area of the drift. This area was computed by the formula

$$A = 36\ H^{4/3} \tag{8}$$

and the corresponding water equivalent content (W_s) in cubic feet water per foot of width is

$$W_s = 18\ H^{4/3}$$

if the snow density is 0.5. (9)

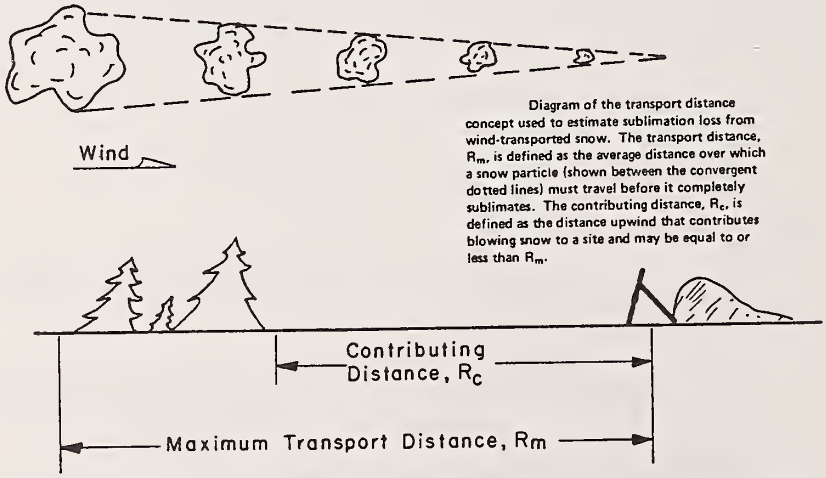


Diagram of the transport distance concept used to estimate sublimation loss from wind-transported snow. The transport distance, R_m, is defined as the average distance over which a snow particle (shown between the convergent dotted lines) must travel before it completely sublimates. The contributing distance, R_c, is defined as the distance upwind that contributes blowing snow to a site and may be equal to or less than R_m.

FIGURE 42: TRANSPORT DISTANCE CONCEPT (190)

Upon evaluating the snow fence patterns and heights, it was concluded that properly engineered snow fence systems are a powerful tool for snow control, and it is unfortunate that earlier applications of improperly designed fences have made the engineer skeptical of their potential. The benefits of improved visibility and reduced ice formation have been appreciably advanced with results of the Wyoming I-80 system.

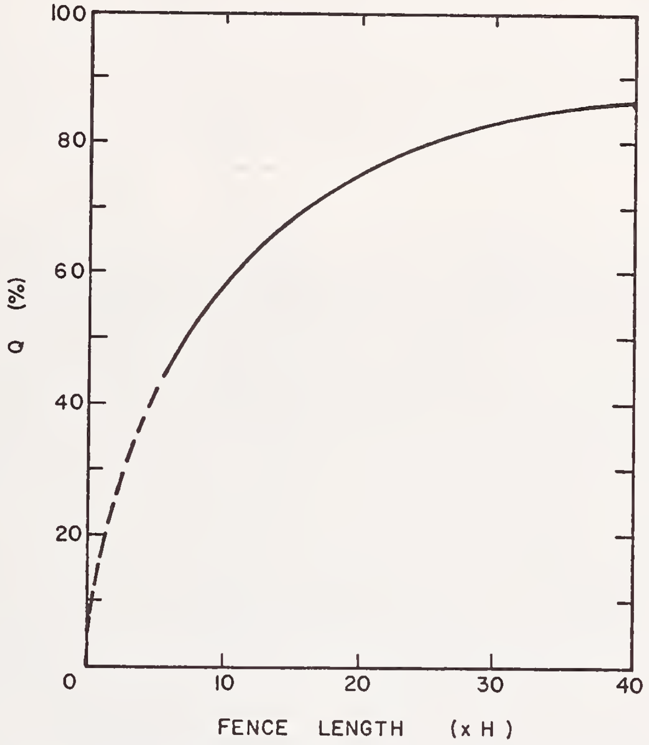


FIGURE 43: TOTAL STORAGE CAPACITY AS A FUNCTION OF FENCE LENGTH

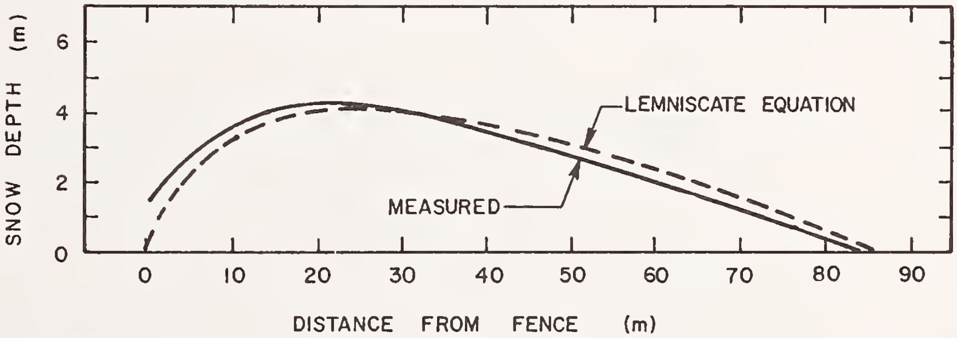


FIGURE 44: AVERAGE DRIFT PROFILE AT SATURATION COMPARED WITH THE LEMNISCATE EQUATION

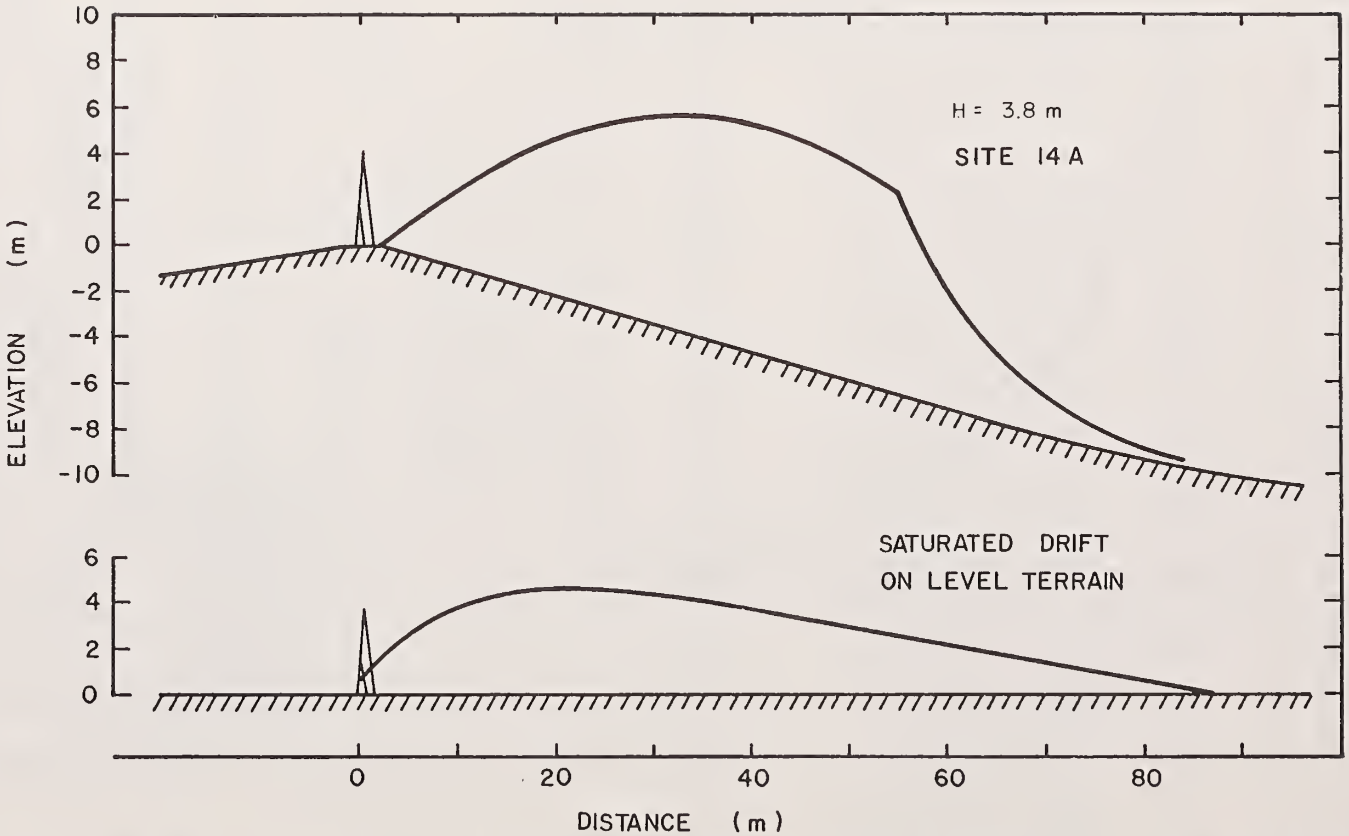


FIGURE 45 CROSS SECTION OF THE LARGEST DRIFT YET MEASURED BEHIND THE I-80 FENCES (190)

Roadway Design Considerations

Highway design will affect the efficiency with which the snow fighter can perform his duties. Optimum or proper placement of turnarounds on divided interstate, to adequate snow storage on rural two-lane roads may have a significant impact on routing efficiency to the type of equipment to move snow and the time required to keep up with impending storms.

Better roads in "Snow and Ice Control Techniques at Interchanges" [42] reported several design criteria that do not necessarily compromise safety to the highway user, but are important in reducing snow removal costs which are an accumulating expense each year.

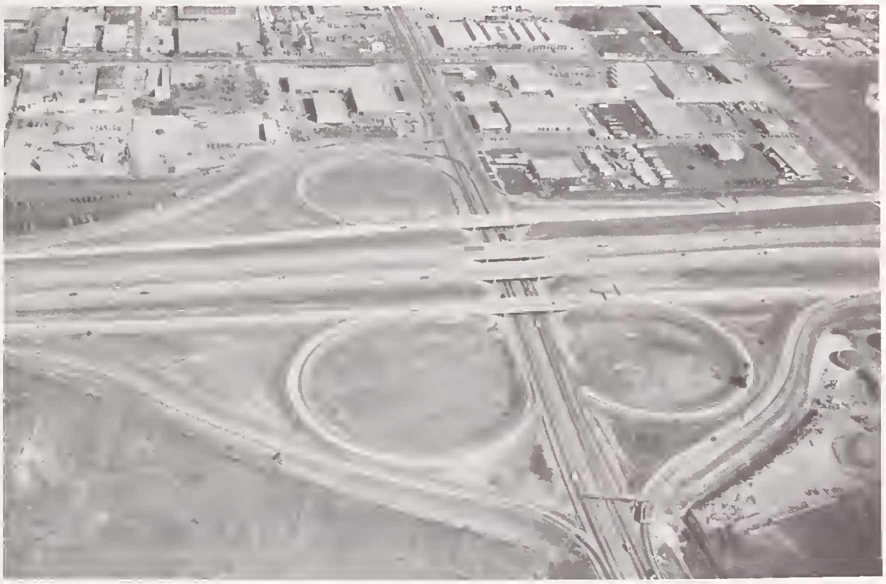


FIGURE 46: I-15 AT 21st SOUTH STREET (ALT. US 50). SALT LAKE CITY, UTAH (Courtesy Utah Department of Transportation)

Interchange Design

Geometrics/Cross Section

Interchange geometrics may contribute to several significant snow and ice control problems.

Among the factors to be considered are:

1. Cross Sections
2. Crossovers
3. Side Slopes

4. Snow Storage

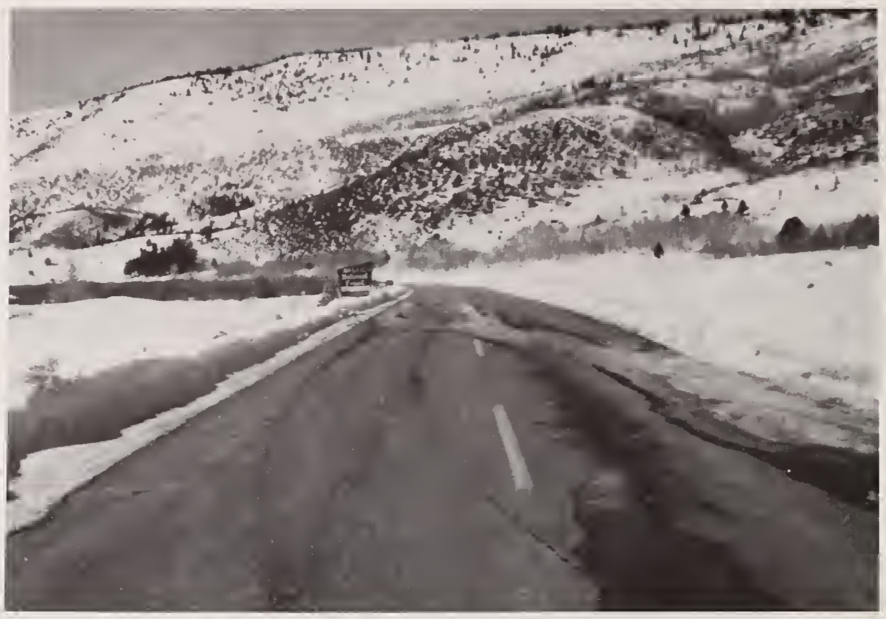


FIGURE 47: TYPICAL CROSS-DRAINAGE OF SNOW MELT PROBLEM
(Courtesy Utah Department of Transportation)

Problem: Cross-drainage of snow melt across super elevated ramps are subject to refreezing.

Design Technique:

1. Reverse slope on shoulder and in gore area
2. Add catch basin in gore to accommodate drainage

Gore area which allows snow melt runoff across pavement, gore should be graded slightly toward a flush mounted drain located in the center.

Drainage may be more easily accomplished on the low side of super elevated ramps by using curb and gutter to control the flow.

A preferred drain grate design will have a painted "teardrop" on the pavement to indicate location of drain when it is covered by a windrow of snow.

For potential icing hazard from snow melt if freezing temperatures should occur, a reverse shoulder slope is needed.

Geometrics/Crossovers

The advantage of crossovers are increased convenience and reduced deadhead for maintenance and emergency vehicles. The major disadvantage is that a severe safety hazard is created. Public traffic will continue to use the crossover in spite of signs making turnarounds illegal.

Crossovers installed on narrow medians provide limited area for large vehicles to clear the traveled portion of the roadway. Diagonal or modified "S" crossovers are an alternative solution. Existing underpass or overpass structures may also serve as crossover locations.

Geometrics/Side Slopes

Severe slopes and grade changes cause drifting into the ramp pavement. If practical and economical, slopes should be flattened to at least 4:1 and preferably 6:1 to eliminate drifting. A windbreak of vegetation planted part way down the upwind slope would help control drifting and keep the pavement clear.

Geometrics/Snow Storage

Fencing installed close to the shoulder reduces snow cast and requires shoulders to serve as permanent snow storage areas.

The alternative solutions are to haul the snow elsewhere or remove by snow blower.

Lack of storage area in regions of heavy snowfall results in a relatively narrow lane width on ramps. Reduced driver sight distance occurs because of the windrow in the gore. A wider gore would reduce this excessively high windrow.

Careful attention to grading and drainage at ramp separations is required on structures because of their use as snow storage areas and the hazard which frozen melt water would provide.

Heavy reliance upon melting by the use of chemicals is the standard operational procedure.

Wide, depressed gores and wide shoulders next to a retaining wall are good design features of a ramp area.

The narrow shoulders and median of depressed interchanges severely limit the snow storage area.

Snow storage and plowing problems are caused by the use of a raised and crowned gore, by the use of curbs and by the use of guardrail close to a ramp.

The raised gore complicates plowing and causes snow melt to flow across the ramp pavement.

Drains

Preferred design is to locate the drain within the traveled portion of the pavement so that it will be cleared as the pavement is plowed. The design should provide a means of elevating the grate for future resurfacing.

Guardrail

The problems created by guardrail are reduced snow cast, formation of windrows, and drifting onto the pavement.

Under certain wind conditions, a guardrail may be beneficial in controlling drifting and creating drifts off the pavement. Where the guardrail is omitted, drifting can be seen extending further onto the ramp shoulder.

If the guardrail is placed close to the ramp surface, snow storage area is severely restricted. Snow must be blown over the guardrail or hauled elsewhere between storms in order to eliminate a reduction in pavement width by snow gradually extending out into the driving lane.

On median approaches to bridge structures, it is important to provide as much snow storage areas as possible. If storage is limited then snow must either be transferred across the roadway, plowed ahead across the sturcture, blown over the guardrail by use of a snow blower, or loaded on trucks for transfer elsewhere.

Cable guardrail allows increased snow cast and is preferred from the snow removal point of view. This type of guardrail, however, does not completely eliminate the windrow problem in areas of heavy snowfall.

Appurtenances

The use of a raised gore area and curbs create obstacles to plowing. By constructing signs and other appurtenances in the gore, its use for snow storage is restricted. Whenever possible, signing should be on existing overhead structures or on sign supports set in back of the usable shoulder.

Extension on pavement delineators (snow poles) make them visible to plow operators in heavy snow.

Rumble strips, although a potentially successful means of delineation to the vehicle driver, may become damaged by plow blades or cause damage to plow blades. The area cannot be plowed clear and melt from the remaining snow will continue to flow across the ramp until exhausted.

During clean-up operations when the snow is winged back to make room for future storms, delineators and signs will reduce the effective distance or efficiency of winging.

Damage to appurtenances is not unusual and maintenance time and expenditures are required for repair.

Delineators located within or close to the shoulders provide obstacles to plowing during clean-up operations. The plow must turn out into traffic in order to go around each delineator or sign.

Fences can seriously reduce the available snow storage area. Damage to the fence may result from the heavy snow and ice placed against it. Light standards and signs placed near the shoulder create obstacles to plowing. These appurtenances should be moved closer to the fence to allow increased storage and reduce the conflict with traffic and plowing operations.

During conditions of wet, blowing snow, traffic control signs may become totally obsecured. This produces a safety hazard as well as an inconvenience to the motorist unfamiliar with the area.

Structures

Bridge guardrails and parapets reduce snow cast which in turn creates windrows on either side of the bridge deck. These windrows produce cross-pavement drainage and the potential for drifting. Grading and drains are required to accommodate this snow melt.

Bridge drains are a necessity in order to accommodate snow melt. They should be flush with the pavement so that the plow blade will plow it clean.

Complex, elevated interchanges present a particularly difficult snow and ice control problem. Ramps are super elevated, underlying roadways prevent casting through the guardrail and limited right-of-way reduces snow storage areas to a minimum. A combination of all problems requires that attention be given to the design requirements for snow removal.

As a result of limited storage area on bridges, snow may be cast over the bridge railing onto the underlying pavement. Where this is a problem and where excessive drifting will not result, a solution technique is to use solid barriers or baffles to confine the cast snow to the bridge deck or sidewalk.

Liaison between representatives of maintenance, in addition to design, construction, materials, traffic and right-of-way should be promoted during the planning and construction phase of highway projects. This encourages input and interaction by maintenance to help solve problems not apparent during the course of routine design or construction. This may aid in averting the practice of changing turn around locations, making arbitrary access to deicing material stockpiles, re-molding drainage appurtances etc., soon after maintenance becomes responsible for the highway segments.

Weather Forecasting and Communications

Most highway agencies responsible for winter maintenance have or make use of weather forecasting to aid in preparation efforts before a storm begins. Northfield, Illinois makes use of a certified consulting meteorologist firm to supply advance warning information about storms. They also recommend action and comment on problems the maintenance force may face. This advice includes: spread salt, or not; even pre-spread on occasion; begin plowing, and more importantly, what is expected to happen during the storm [43].

Weather forecasting has the advantage of predicting to some extent when the storm will begin, how long it will last, how much will accumulate, what the temperature ranges will be, storm speed, direction, snow wetness, and general progress of the storm as it approaches a particular area. Before-hand information on the storm characteristics may help in critical decisions on pre-storm planning, start-up time, in-storm operations such as whether or not to apply chemicals, implementation of a chain law if applicable and scheduling men to handle the entire duration of the storm. It is important to know the temperature pattern of a storm. If it starts cold, cold enough that salt is not effective, then packing may occur. If it ends with a drop in temperature, then clean up operations as soon as possible should begin to avoid the more difficult task of loading cold snow or pushing back the cooler snow from areas such as shoulders.

In January 1967, Chicago experienced a blizzard which dropped 58 cm (23 in.) of snow within seventeen hours, immobilizing the city for days and caused the loss of an estimated $180 million to businessmen and wage earners [44]. As a result, Mayor Daley ordered the department of streets and sanitation to put together a massive snow-clearance program. Primarily, this program involved a centralized planning center. The planning center is manned 24 hours a day, year round. When it is not snowing, the facility handles communications for the eight bureaus of the department. When quick mobilization is needed to fight an impending storm, a teletyped message can be relayed to all salt storage and equipment locations in less than five minutes.

This section also contains Snow Command's records and maps (the department keeps track of the nation's storms even through its official weather warnings come from a private forecasting firm), a storm's progress. A bank of desks from which, among other things, equipment operators are called out by means of pre-coded cards that are inserted into telephone slots that automatically dial the numbers. When there is no snow, this section is used to direct other administrative orders.

Off season, the operators assign department trucks to police auto-towing calls, street-light repair, traffic accidents, street cave-ins, cases of missing traffic signs or barricades, removal of bulk refuse and debris, and removal of street dirt from street cleaning.

According to city officials, praise of the city's snow removal has increased, complaints and accidents are down, and the equipment operators are often able to suspend operations within an hour of a storm's end [44].

Adequate communications during a storm will increase the efficiency of snow and ice removal operations. Complete radio equipped trucks are not uncommon for many counties and states. For instance, Cattaraugus County in New York [45] has reported increased efficiency and better control of snow removal operations with a 100 percent radio equipped maintenance department.

Radio communications have been found helpful in situations where snow fighting equipment breaks down, keeping up on the storm's progress and notifying equipment operators of storm completion versus monetary lulls between storm fronts.

Introduction - Materials

The increased reliance on the motor vehicle in past years has been responsible for the insistance by motorists that streets, roads and highways be available for travel during adverse weather conditions of snow, ice and freezing temperatures. Compliance with these needs has resulted in a large increase in the use of sodium and calcium chlorides to melt ice or prevent its formation on pavements.

Intensive applications of chloride deicing salts have supposedly made winter driving safer but have been responsible for various problems. Among these problems are damage to portland cement concrete pavements and particularly bridge decks, corrosive damage to steel in automobile and truck bodies, and pollution caused by increasing concentrations of sodium and chloride in roadside soils, in industrial and drinking water and in other bodies of water [46], [47], [48], [49], and [50].

The destructive effects attributable to salt use have led to efforts on the part of many state highway departments to avoid excessive and unnecessary use of salt and adopt judicious methods of application. But problems presist even with judicious salt application. Some agencies have investigated the use of alternative deicing methods.

In 1973, the Federal Highway Administration (FHWA) and the Transportation Research Board (TRB) jointly set up a Maintenance Research Needs Study. Of 26 problem statements drawn up by the study's steering committee, three related to winter maintenance and one to the minimizing of the use of deicing chemicals during winter maintenance. It was generally agreed that too much salt is being used and the latter study was given a high priority in 1975.

Chemicals are applied to highway pavements to accomplish three things: (1) prevent formation of ice, (2) melt ice that has formed, and (3) prevent buildup of snowpack [51].

In this section, a review of commonly used chemicals, abrasives, and combinations is presented along with present practices of material storage, hauling and pre-mixing. Also, since materials applied to the roadway are to counteract undesirable conditions activated from snow or ice, a review of general snow and ice characteristics is included [51].

Characteristics of Snow and Ice

Snow and ice properties pertinent to winter highway maintenance were summarized in 1965 by D. L. Minsk with emphasis on applying this knowledge to snow and ice problems found on roads and airfields [50].

Snow and ice are forms of the solid phase of water, yet they differ considerably in their properties. Both are unusual, however, in that they exist at temperatures close to their melting point. In the United States, the lowest temperature ever recorded was -56°C (-70°F) (at Rogers Pass, Montana), but temperatures in the more populated areas seldom drop below -40°C (-40°F). This is only 22°C (72°F) from the solid-liquid phase change, quite a small amount in comparison with other familiar materials. This difference is narrowed even more during the frequent periods when the temperature fluctuates by only a few degrees about the freezing point. Most of the properties of snow and ice are strongly influenced by temperature, and the inherent thermodynamic instability is characteristic. The properties also change with time by a process called snow metamorphism. They can be grouped broadly into mechanical, thermal, and electrical.

The stresses (mechanical) causing structural collapse can result from tension, compression, or shear forces. The bonds between the snow crystals break, resulting in a sudden loss of cohesion. In tension and pure shear, the snow mass often breaks along a plane; compressive failure sometimes causes it to crumble, though conical failures typical of shear planes frequently result during unconfined loading.

Tensile strength of low-density snow is low and shows wide scatter. The dependence of tensile strength on both temperature and density is shown in Figure 48. Tensile strength for high-density snow is given by Butkovich as [54]

$$\gamma_T = 503\ (\rho - 0.37)\ [(1 + 2.88\ (\rho - 0.37)^2] \qquad (10)$$

where

γ_T = tensile strength (psi) at -10°C (14°F), and

ρ = density @ 0.4 gm/cu cm.

Crushing strength is the unconfined uniaxial compressive strength. The same form of equation was used by Butkovich for snows with density greater than 0.4 g/cu cm, but it was simplied to:

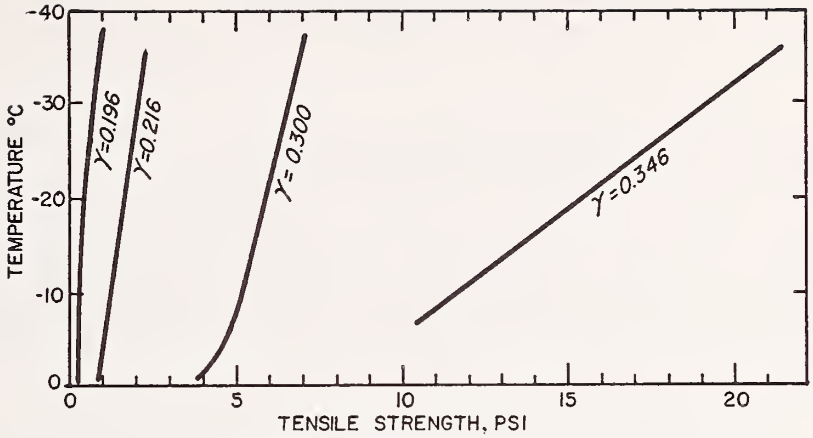


FIGURE 48: INFLUENCE OF TEMPERATURE AND DENSITY OF SNOW ON TENSILE STRENGTH(197)

$$\gamma_C = 1418\ (- 0.39) \qquad (11)$$

where

γ_C = crushing strength (psi) at -10°C (14°F), and

ρ = density @ 0.4 gm/cu cm.

Crushing strength is about twice the tensile strength. It is also very low in low-density snow. However, if the snow is confined during compression, it collapses in stages until a density of 0.5 gm/cu cm (31.2 pcf) is reached. At this point the snow grains are closely packed, and stress then increases very rapidly because any further densification must occur not by breaking of bonds but by deformation of an increasing number of snow grains [55].

Shear strength of snow is much like the tensile strength. An equation derived by Butkovich [54] for high-density Greenland snow is similar to that for tensile strength [53]:

$$\delta_S = 333\ (\gamma -0.37)\ [1 + 7.03\ (\gamma - 0.37)^2] \qquad (12)$$

where

δ_S = shear strength (psi) at zero lateral pressure and -10°C (14°F), and

γ = density @ 0.4 gm/cu cm.

Coulomb's law of friction, familiar in soil mechanics, has been applied to snow mechanics. This law states that:

$$S = c + p \tan \phi \qquad (13)$$

where

S = shear strength,
c = cohesion,

p = normal pressure, and

ϕ = angle of shearing resistance.

At zero normal pressure, $S = c$; the shear stress under this condition is commonly called cohesion.

Coulomb's equation is not valid for many snow conditions because the sum of the cohesion and pressure terms may not be a straight line. The equation is applied in avalanche mechanics and the performance of oversnow tracked vehicles, for in these cases of high rapid loading the grain bonds break by structural collapse and the material behaves somewhat like sand.

Work of disaggregation of snow is the minimum work that must be done to break up a snow mass into its individual grains. The term is only significant when applied to snow of density less than 0.5 gm/cu cm.; above this value not only the grain boundaries but the snow crystals themselves are ruptured. An illustration of how metamorphism changes snow properties, that of the increase in the work of disaggregation resulting from the increase in the number and size of bonds, is shown in Figure 49.

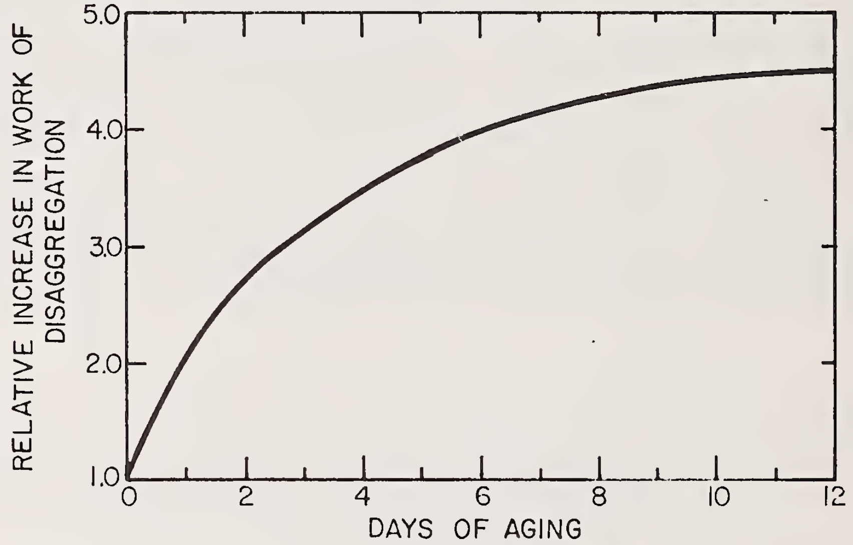


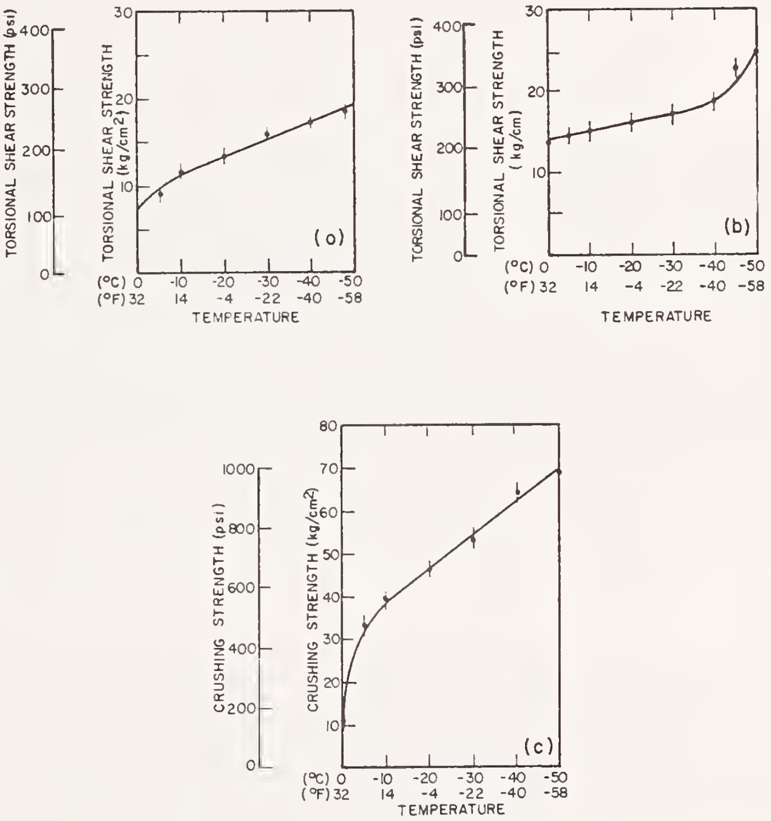
FIGURE 49: INCREASE IN WORK OF DISAGGREGATION OF SNOW RESULTING FROM SNOW METAMORPHISM (198)

Because of the low value of specific heat of air, the specific heat of snow is almost entirely due to the ice. Though it varies with temperature and purity of snow, a value useful for engineering purposes is 0.506 cal/gm°C. (It is also 0.506 BTU/lb-°F)

Thermal conductivity of wet snow is zero since it is isothermal. Heat transfer under this condition can occur by transmission of radiant energy or by percolation of melt water and subsequent refreezing with release of the latent heat.

Ice is generally a more serious problem than snow in its effect on roads, runways, and structures, and because of its greater adhesion to surfaces, it influences traffic movement on roads and airfields and causes failure of power lines and structures. Also, as northern state highway departments have found, its removal or control, short of removal costs are 10 to 15 times as much as snow removal. Snow can almost always be handled and ultimately removed, whereas ice removal from extensive areas is sometimes nearly impossible.

The crushing, torsional shear, and tensile strengths of ice were determined by Butkovich [55] for clear lake ice, snow ice, and artificial (commercial) ice. The strengths of commercial ice as a function of temperature are shown on the graphs of Figure 50 [50].



(a) Torsional Shear Strength, Shear Force Parallel To Long Axis Of Prismatic Crystals; (b) Tensile Strength, Load Applied Normal To Long Axis Of Prismatic Crystals; and (c) Crushing Strength, Load Applied Normal To Long Axis Of Prismatic Crystals. (52)

FIGURE 50: STRENGTHS OF COMMERIAL ICE AS FUNCTION OF TEMPERATURE

Considerable work has been done in the search for materials or surface treatments to which ice will not adhere. Jellinek [56] reported that on rough stainless steel ice had a mean strength of adhesion of about 60.46 gs cm (86 psi) and on mirror finish stainless steel of 27.77 gs cm (38 psi).

On more familiar materials, it has been reported that a layer of concrete was torn off when an attepmt was made to remove ice from its surface. In general, on metals and pavement materials, the strength of adhesion of ice is greater than its tensile strength.

The latent heats associated with the changes of phase water undergoes in all its common forms are summarized in Table 15. It is appropriate to mention here the mechanism by which chemicals melt ice or snow. Any material that will dissolve in a liquid will lower the freezing point (and, incidentally, the boiling point) of the liquid.

TABLE 15: THERMODYNAMIC VALUES OF WATER PHASE TRANSITIONS [50]

		Thermodynamic Value	
		Cal/g	BTU/lb
Solid = liquid (Liquid - solid)	Heat of fusion (Heat of solidification)	80	144
Liquid = vapor (Vapor - liquid)	Heat of vaporization (Heat of condensation)	596	1,220
Solid = vapor	Heat of sublimation	676	1,364

This freezing point depression is expressed by Raoult's law, which states that the vapor pressure over a solution is reduced in proportion to the amount of the solid (the solute) dissolved in the solvent, or

$$\frac{P_o - P}{P_o} = \frac{n_2}{n_1 + n_2} = N_2 \tag{14}$$

where

P_o = vapor pressure of pure solvent,
P = vapor pressure of solution,
n_2 = quantity of solute (moles),
n_1 = quantity of solvent (moles), and
N_2 = mole fraction of solute.

The way in which the reduction of the vapor pressure lowers the freezing point can best be explained by referring to a plot of temperature vs vapor pressure, where the system considered is water as the solvent and a salt as solute. (Figure 52) At temperatures below T_o water has a higher vapor pressure than ice, and because a substance at a higher

> *vapor pressure than ice, and because a substance at a higher energy level will seek to transfer its energy to one at a lower level until their energies are equal, the water will freeze. Addition of a salt to the water will give a lower vapor pressure for the solution than the solvent, which is shown by the salt solution curve. In dilute solutions this curve is approximately parallel to the solvent curve in the vicinity of the freezing point. The freezing point, where the solid, solvent, and solution can exist in equilibrium, has now been displaced to the intersection of these two curves. This is lower than the freezing point of the solvent by* ΔT*, the freezing point depression* [50].

Four mechanisms of ice formation on pavements will be described: (a) radiation cooling, (b) freezing of supercooled water, (c) freeze-thaw of compacted snow, and (d) icings. No significance should be attached to their order of listing, for their relative importance depends on the geographical region and climatic conditions.

Any body will radiate its energy to another body having a lower temperature. The night sky is nearly a perfect black body, and a pavement or structure exposed to the sky radiates energy to it. If the radiating body's heat source does not replace the heat as fast as it is lost, cooling occurs. The temperature of a pavement can drop below freezing even though the air temperature is considerably above freezing. Water vapor in the air deposits on the cold surface and freezes, the rate and quantity depend on the amount of moisture in the air and the rate at which the heats of condensation and fusion of the water vapor can be removed. Bridge decks are notorious for the problems they cause because the underside loses heat rapidly to the air, whereas pavement and soil have large masses under them which supply heat by conduction. The ice forms in discrete particles, and since the entire surface is not completely covered, this type of ice is easier to remove than the others. It is like a cover of marbles a few layers thick; only a small portion of the area of each sphere in the bottom layer touches the pavement surface and the second and higher layers do not touch the surface at all. A term frequently applied to this type of ice is surface hoar or, more commonly, "hoarfrost."

This merely refers to the freezing of ponded water on a pavement. The term originally was limited to ice formed from groundwater flowing onto a pavement, but by extension it also means water from any source. Thus, melt water resulting from poor drainage of a pavement or rain impounded by snow windrows can cause icings. This ice is generally well bonded to the pavement, and, in addition, its thickness may exceed that of the other types of ice.

If the pavement surface is at or below 0°C (32°F), rain falling on it may have an opportunity to freeze, depending on a number of factors. Conditions favoring the formation of so-called glare ice or glaze (a homogeneous clear ice cover) are a slow rate of freezing, large drop size, high precipitation rate, and only a slight degree of supercooling. The rain has an opportunity to flow over the surface before freezing, forming a smooth, tightly bonded cover. This is the hardest type of ice to remove because of its intimate contact with the underlying base material. Glaze usually forms at air temperatures between -2.8°C and 0°C (27°F and 32°F), though some cases have been reported of its formation at temperatures as low as -20°C (-5°F) and as high as 28°C (37°F) [57]. Evaporation may play a part in the freezing process, for a simple calculation shows that evaporation of 0.126 gm of water will freeze 1 gm of water at -5°C (-21°F) falling on a 0°C (32°F) surface [58].

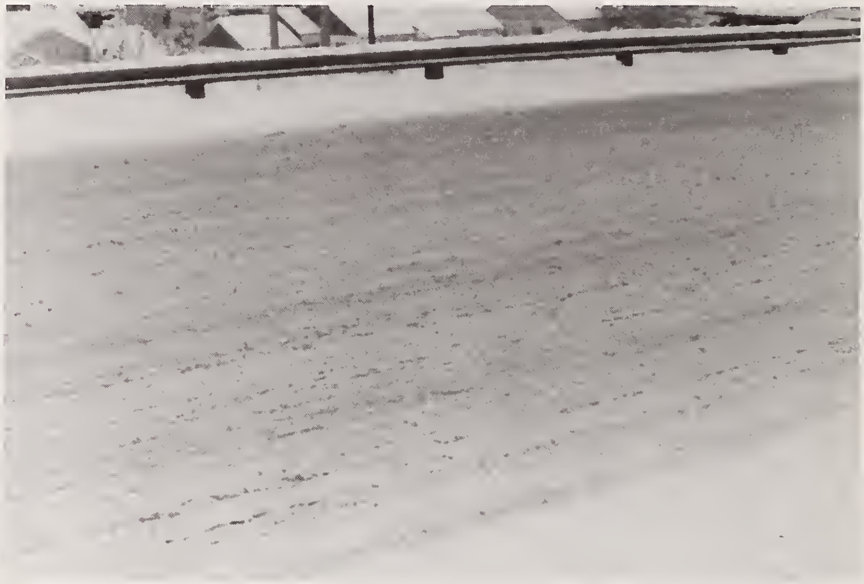


FIGURE 51 COLD SNOW COMPACTED BY TRAFFIC

Compaction of snow by the passage of wheeled vehicles will not cause a strong bond to develop between the snow and pavement at low temperatures. However, if this compacted layer melts, an ice layer can form which tightly bonds the snow to the pavement. The mechanical strength of this bond can be as high as that of glaze, which is stronger than the tensile strength of the compacted snow. Therefore, the layer is difficult to remove completely by mechanical means.

Rime ice may be found in some locations, though generally not on pavements except on fills in exposed locations. It is formed by supercooled water droplets impinging on a surface whose temperature is below the freezing point and whose mass is large enough to dissipate the heat of fusion without a rise in temperature above the melting point. The droplets freeze almost instantaneously on the surface and retain their spherical or near-spherical shape. A somewhat loose aggregation of lightly bonded grains builds up on the surface. Amount of water vapor present, droplet size, air temperature, and wind speed influence the density of the rime accumulation.

Many properties of snow are functions of its density and temperature. New snow, however, begins to change its structure immediately after being deposited, and the density increases steadily to a limiting value dependent on air temperature, wind, humidity, incident radiation, and depth of cover. Density of snow is important in the clearing process since it determines the weight of material that must be handled. Since density increases with time, much extra work can be saved by removing snow during or immediately after a snowfall. Other properties that can be used to characterize the state of a snow cover and can be measured in the field fairly easily, are hardness and, to some extent, water content.

Chemicals

A major problem of highway maintenance departments in northern areas concerns keeping roads usable during the winter months; attempts are aimed at providing roads made slippery by ice and snow safe for normal traffic speeds. There are two principal methods of treatment utilized by most maintenance crews on icy highways. If the immediate use of the highway is of prime importance the use of abrasives to furnish traction is one solution. In some cases this may not be a complete solution however, as the abrasive may be whipped off by traffic or wind and the ice will remain. Another treatment is to remove the ice or compacted snow which has caused the slippery condition. This can be accomplished by the application of chemicals which lower the melting point sufficiently to transform the ice into water which then drains off [61]. Chemicals are applied to highway pavements to accomplish three things: [4])

(1) Prevent formation of ice
(2) Melt ice that has formed, and
(3) Prevent buildup of snowpack

The two chemicals commonly used for this purpose are sodium chloride and calcium chloride. [61]

There are alternates to the commonly used calcium chloride and sodium chloride. Some of these include: urea, urea-formamide mixture, tetrapotassium pyrophosphate (TKPP), ethylene glycol, ammonium acetate, sucrose, ethanol, magnesium chloride, methanol, UCAR II, potassium chloride, ammonium sulfate, ammonium nitrate (fertilizers), aluminum chloride and lithium chloride [4], [46] and [60].

Some of the alternative chemicals which have been proven effective are formamide, urea, urea-formamide mixture, tetrapotassium pyrophosphate (TKPP), ethylene glycol and ammonium acetate. All of these are susceptible to biodegradation. This process results in products which may promote unwanted algae or weed growth; are toxic to aquatic life if present at certain concentrations; and consume large quantities of oxygen in the water during degradation, leading to asphyxiation of aquatic life. However, climatic conditions influence the manner in which these processes occur. Thus, during the cold winter months, only a small amount of biodegradation is expected and the process poses no problem. It is in the warmer months that care should be exercised that relatively high accumulations of biodegradable deicing materials are not available for degradation in areas sensitive to pollution and toxicity. With the foregoing considerations, the following alternative deicing chemicals are recommended for further evaluation and perhaps modification to improve their functioning: Formamide, urea, tetrapotassium pyrophosphate (TKPP), a formamide - urea-water mixture and a tripotassium phosphate-formamide mixture [4].

The physical characteristic of chlorides and other deiciers which enables them to remove ice from highways is their ability to lower the freezing point of water and thus prevent and reverse the formation of ice. This lowering of the freezing point is caused by a lowering of the vapor pressure of the solution. Whenever a substance exists in two states which are in contact with each other, as for example water and ice, thereis a constant interchange of molecules between the two states. This interchange of molecules creates what is called vapor pressure.

If the vapor pressure of the solid is greater than that of the liquid, more molecules will leave the solid state than will return and the solution will become entirely liquid; and conversely if the vapor pressure of the liquid is greater than that of the solid, more molecules will enter the solid state than will leave and the solution will become entirely solid. The freezing point is that point at which the vapor pressure of the liquid equals the vapor pressure of the solid.

In a solution, if the solute is more soluble in the liquid than in the solid, the solute molecules will remain in the liquid, resulting in fewer molecules of solvent for a given volume and hence a lower vapor pressure. When the vapor pressure of the liquid becomes lower than that of the solid, the solid state will change to liquid until a new equilibrium point is reached. Both calcium chloride and sodium chloride are more soluble in water in the liquid state than in the solid state.

Vapor pressures decrease with a decrease in temperature and values for pure ice and for pure water have been determined for various temperatures. The amount of reduction in vapor pressure caused by the addition of various solutes has also been determined. Using this information, the freezing point of a solution can be found in the following manner:

1. Compute the strength of the solution in terms of gram molecules of salt per liter of water.
2. Using standard physical chemistry handbook tables, determine the percentage reduction in vapor pressure of this solution.
3. Find the temperature at which the vapor pressure of pure water when reduced by the percentage determined in (2) equals the vapor pressure of pure ice.

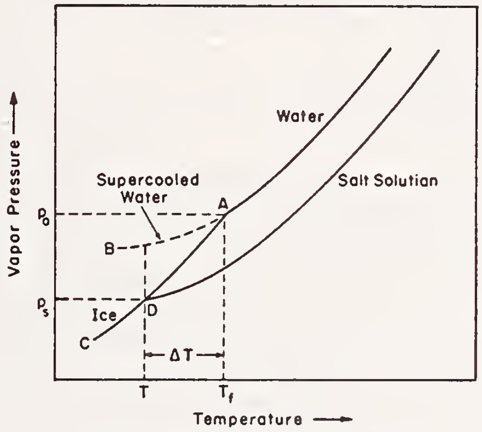


FIGURE 52: SALT SOLUTIONS MELT ICE BY DEPRESSING THE FREEZING POINT THROUGH THE MECHANISM OF REDUCING THE VAPOR PRESSURE (4)

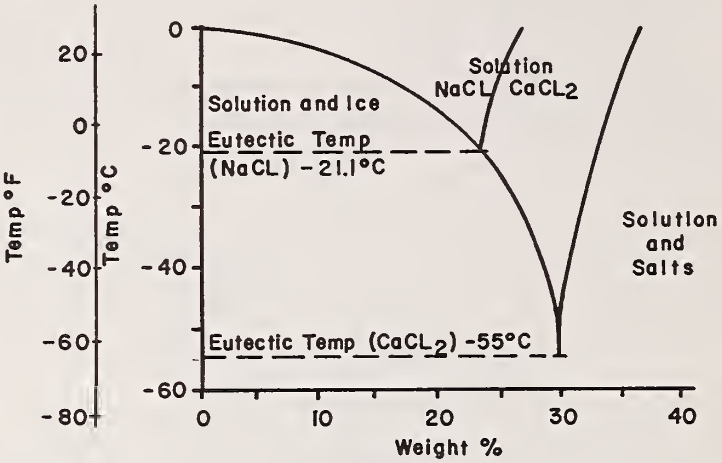
Table 16 summarizes the eutectic temperature and cost for various deicing chemicals:

TABLE 16: EUTECTIC TEMPERATURE AND COSTS FOR VARIOUS DEICINC CHEMICALS

CHEMICAL	EUTECTIC TEMP.		CONCENTRATION AT EUTECTIC TEMP.	COST* SALT LAKE CITY, UT.	
	Deg. F	Deg. C	PERCENT	Metric	Ton
Sodium Chloride	-6	-21.1	23.3	9	10
Calcium Chloride	-67.0	-55	29.8	31	34
Potassium Chloride	-13	-10.6	19.8	27	30
Ammonium Sulfate	2.2	-19	38.3	28	31
Ammonium Nitrate	1.0	-17.2	41.2	--	--
Urea	11	-11.7	32.6	82	90
Alluminum Chloride	-67	-55	25.3	290	320
Lithrium Chloride	-112	-80	25.3	1,579	1,740
TKPP				--	--
Ethylene Glycol	Not Available			--	--

*In Dollars per Ton, 1976

Sodium chloride (rock salt) and calcium chloride are the most commonly used deicing chemicals. Sodium chloride, because of its relatively low-cost and clacium chloride, because of its rate of effectiveness at lower temperatures. Because some substances are less soluble than others, adding more material will not depress the freezing point the same amount for all substances. The solubility of sodium and calcium chloride is shown in a phase diagram Figure 53.



SOLUBILITY CURVE

FIGURE 53: PHASE DIAGRAM FOR SODIUM CHLORIDE AND CALCIUM CHLORIDE (4)

Adding salt to the same quantity of water calls for moving to the right along the horizontal axis. As we do so, so drops the freezing point (labeled "solubility curve" because it divides the region where salt is completely in solution from that where ice will form). The freezing point will continue to drop until the salt concentration reaches about 23 percent. Here the freezing point reaches a minimum of -21°C (-6°F) called the eutectic point, and adding more salt only serves to raise the freezing point. If the temprature is lowered below the eutectic point, salt will no longer remain in solution but will solidify outside the ice boundary.

The phase diagram for calcium chloride is similar, but at low concentrations the curve is flatter; i.e., the freezing point depression is less. The drop in freezing point increases rapidly as the concentration increases and the curve becomes progressively steeper, until the eutectic point is reached at about 30 percent $CaCl_2$ and a freezing point of -55°C (-67°F).

When water freezes it gives up heat in the amount of 80 calories per gram (144 Btu/lb) - the latent heat of fusion. Melting is the inverse process, and heat must be added to ice to melt it. In the case of ice on a pavement, heat can come from the air, from solar radiation, or from the pavement and its corresponding heat reservoir. In all cases, however, heat will only flow downhill that is, from a hot to a cold body. When a deicing chemical is spread on ice and goes into solution, the freezing point is lowered, the vapor pressure is lowered, and additional ice tries to reach the more comfortable state of melting. It will do so only if there is a source of heat available [65].

In summary, the following requirements must be satisfied to melt ice by means of chemicals:

1. Sufficient moisture must be available to dissolve the deicing chemicals.

2. A heat source must be available to provide the energy for melting.

3. The concentration of chemical must not exceed the eutectic composition in order to achieve complete utilization of the chemical [4].

From Figure 53 it is noted that at concentrations of sodium chloride and calcium chloride in the one to five percent range, the melting temperature of the solution is approximately the same. The reason for such notable differences from the effects of adding $CaCl_2$ or NaCl is due to their heats of solution. For example, calculations show that a ten percent calcium chloride solution has a freezing point of approximately -5.5°C (22.1°F) while a ten percent sodium chloride solution has a freezing point of approximately -7°C (19.4°F). This indicates a greater lowering of the freezing point by sodium chloride than by calcium chloride in ten percent solutions; this is in agreement with the fact that there are more ions present per gram in sodium chloride. Field tests indicate better results at low temperatures with calcium chloride than with sodium chloride. This difference is explained by the difference in solubility of the two chemicals at lower temperatures. At 0°C (32°F) it is possible to dissolve only 357 grams of sodium chloride in one liter of water as compared to 595 grams of calcium chloride. This greater solubility produces solutions of greater strength and therefore lower freezing points than those obtainable with sodium chloride.

Two other qualities affect the melting characteristics of these chlorides. Both are concerned with the rate of melting rather than the total amount of melting. The first step in the melting process is the formation of a liquid solution. Here the clacium chloride holds the advantage in that it forms hydrates and thus draws moisture (deliquescent) from the air to form the initial solution much faster than sodium chloride which is not deliquescent.

The other characteristic involved is the heat of solution. Heat is required to transform ice into water and must be supplied from either the surrounding air or from the solution. Heat is also involved in dissolving a solute into a solvent and this heat is called the heat of solution. Calcium chloride in the anhydrous form produces 17,990 calories (71.4 BTU) of heat when 111 grams (24 lb) are dissolved in 7,200 grams (15.9 lbs.) of water. The same amount of calcium chloride in the form with two hydrates (flake) produces 10,040 calories (39.8 BTU). On the other hand, to dissolve this quantity of sodium chloride in this much water would require an additional 2,400 calories (9.5 BTU) from some other source. This would have its greatest effect on the initial melting when the chemical is just going into solution [61].

Use of the eutectic temperature for means of comparing the effectiveness of deicing chemicals is not particularly good. For instance, if a snow depth of only 2.54 cm (one inch) is on a pavement, and if the water equivalent is 1:10, then 2.54 mm (0.1 inches) of water will be present. If a common application rate of sodium chloride at 85 kilograms per kilometer (300 pounds per lane mile) is uniformly applied, then the corresponding salt concentration in the water will be only 0.91 percent. From the sodium chloride phase diagram, Figure 53, 0.91 percent sodium chloride solution will lower the melting point of water approximately .5°C (1°F) not representative of its -21°C (-6°F) capacity for melting water. This is also the case when considering additivies to salt such as magnesium chloride, lithium chloride or others; the corresponding reduction in the freezing point at concentrations resembling that of common highway salting is very slight.

Minnesota Department of Highways conducted field ice removal tests on fifteen combinations of deicing materials within three temperature ranges [62]. Data was collected on ice thickness, actual quantity and location of chemical or abrasive applied, and periodic condition of the ice with regard to amount of ice removed. The materials were sampled for moisture, crusting, and caking for a period of ten months. The test site selected for the ice removal portion of the study was a short section of unopened Interstate highway. The facility is a four-lane divided portland cement concrete paved roadway with bituminous surfaced shoulders.

The ice removal materials selected for comparison in this study were sodium chloride (rock salt and evaporated salt); Type I and Type II calcium chloride flakes; calcium chloride pellets; mixtures of calcium and sodium chloride; a mixture of calcium chloride and sand; and a mixture of sodium chloride and sand.

After performing field tests during the winters of 1960 to 1966 it was decided to eliminate some of the variations in mixtures because the comparative ice removal action between mixtures was not too apparent. The chemicals were applied in a narrow band approximately one meter (three feet) out from the centerline using a chemical dribbler. The application of evaporated salt produced a very narrow band of chemical on the roadway, whereas the mixture of calcium chloride and sodium chloride scattered considerably. Similar scattering was noted with straight calcium chloride pellets as well as with rock salt. The calcium chloride flakes, however, scattered less than the calcium chloride pellets or rock salt but more than the evaporated salt. The width of application of abrasives varied from about one to 3 meters (3 to 10 feet); however, most applications were between one and two and one half meters (3 to 8 feet).

Traffic was simulated over the test section corresponding to approximately 1,440 vehicles per lane per day.

Because this portion of the study had so many uncontrolled variables (such as temperature, wind, and humidity), the results are not repeatable. Therefore, the graph plots presented are considered trends based on mean values of the observed and calculated data.

Figure 54 shows a plot of volume of ice melted by sodium chloride (rock salt) in cubic feet per lane-mile versus time in minutes (vehicles headway remaining constant) for three conditions of average ice and air temperature.

The relative rates of ice removal by calcium chloride and sodium chloride are shown in Figures 55, 56, and 57. The comparison at -8.3°C (17°F) shows that initially the $CaCl_2$ is more effective but as the action progresses the rate of melting decreases whereas that of the rock salt remains more nearly constant up to about one hour and evenutally overtakes the rate of the calcium chloride. As shown in Figure 56, the rate of ice removal by rock salt at lower temperature does not approach that of the $CaCl_2$ pellets. Figures 56 and 56 indicate that sodium chloride is relatively ineffective below -12°C (10°F) in clearing a wheelpath within a reasonable period of time.

Figures 58 and 59 are plots of the comparative ice removal rates of calcium chloride (pellets), sodium chloride (rock salt), and a 1/3 calcium chloride (pellet) to 2/3 sodium chloride (rock salt) mixtures at -8.3°C (17°F) and -12°C (10°F) respectively. The plots show that the chemical mixture removes ice at a rate closely resembling that of straight calcium chloride while still retaining most of the economical advantage of sodium chloride.

The comparative ice removal rates of sodium chloride (evaporated salt) and the 1/3 $CaCl_2$ to 2/3 NaCl mixture at -8.3°C (17°F) and -12°C (10°F) are shown in Figures 60 and 62 respectively. The plots show that initially the rate of ice removal by the evaporated salt is somewhat greater than the pellet-rock salt mixture; however, the evaporated salt is overtaken by the mixture within 30 to 40 minutes.

Figures 61 and 63 are plots of the comparative ice removal rates of abrasive-chloride mixtures and a 1/3 $CaCl_2$ to 2/3 NaCl mixture. As indicated by the curves the abrasive-chloride mixtures are relatively ineffective for ice removal from pavements particularly at the lower temperatures.

It should be noted, for results summarized in Figures 55 through 63 that the data collected during the experimental portion of the study was as few as three points per curve, which may be fitted by any one of several lines. Therefore, these graphs do represent trends which

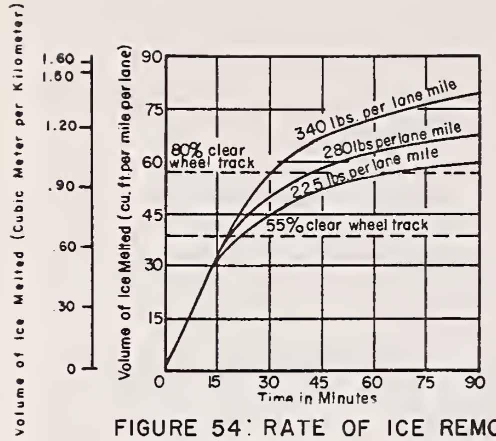


FIGURE 54: RATE OF ICE REMOVAL FOR NaCL(Rock Salt) (62)

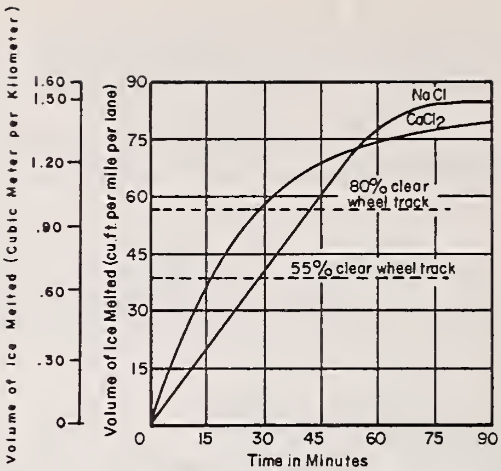


FIGURE 55: RATE OF ICE REMOVAL BY $CaCL_2$ PELLETS AND ROCK SALT AT -8.3°C (17°F) (62)

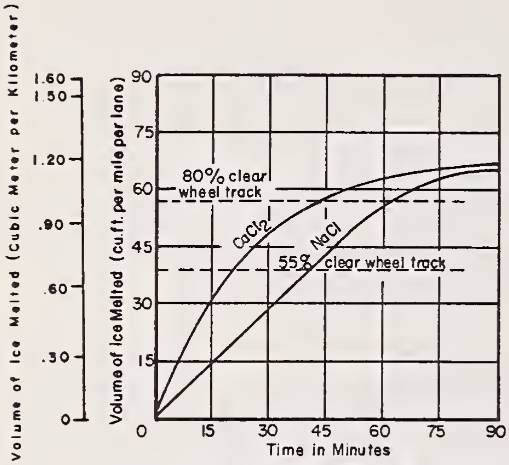


FIGURE 56: RATE OF ICE REMOVAL BY $CaCL_2$ PELLETS AND ROCK SALT AT -10.5°C (13°F) (62)

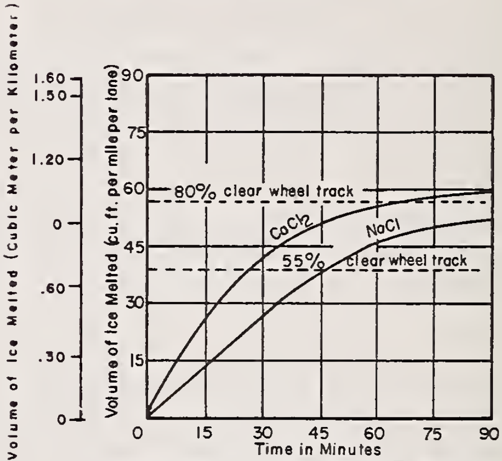


FIGURE 57: RATE OF ICE REMOVAL BY $CaCL_2$ PELLETS AND ROCK SALT AT -12.2°C (10°F) (62)

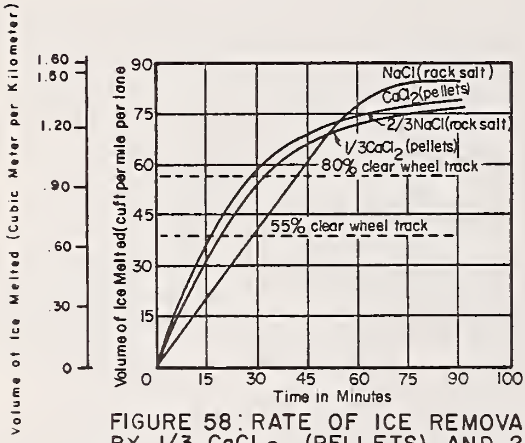


FIGURE 58: RATE OF ICE REMOVAL BY 1/3 $CaCL_2$ (PELLETS) AND 2/3 NaCL (ROCK SALT) AT -8.3°C (17°F) (62)

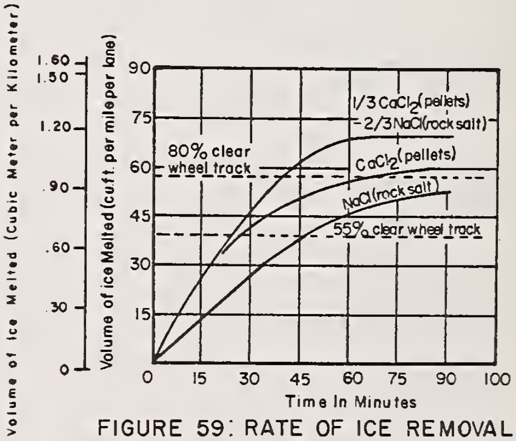


FIGURE 59: RATE OF ICE REMOVAL BY 1/3 $CaCL_2$ (PELLETS) AND 2/3 NaCL (ROCK SALT) AT -12.2°C (10°F) (62)

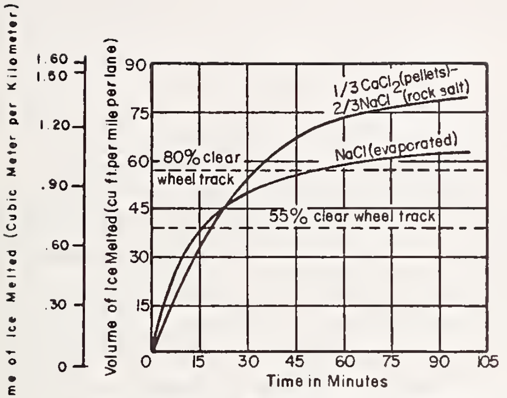


FIGURE 60: RATE OF ICE REMOVAL BY 2/3 NaCL (EVAPORATED ROCK SALT) AND 1/3 CaCL2 (PELLETS) AT -8.3°C (17° F) (62)

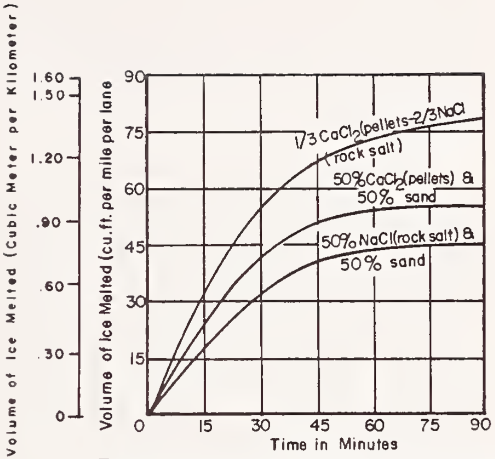


FIGURE 61: RATE OF ICE REMOVAL BY ABRASIVE - CHLORIDE MIXTURES AND CaCL2-NaCL MIXTURES AT -8.3°C (17° F) (62)

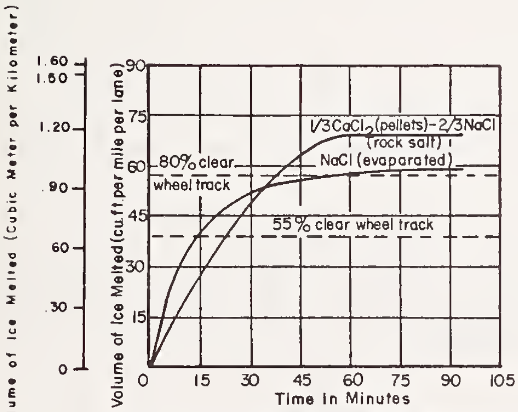


FIGURE 62: RATE OF ICE REMOVAL BY NaCL (EVAPORATED) AND 1/3 CaCL2 (PELLETS) TO 2/3 NaCL (ROCK SALT) AT -12.2°C (10° F) (62)

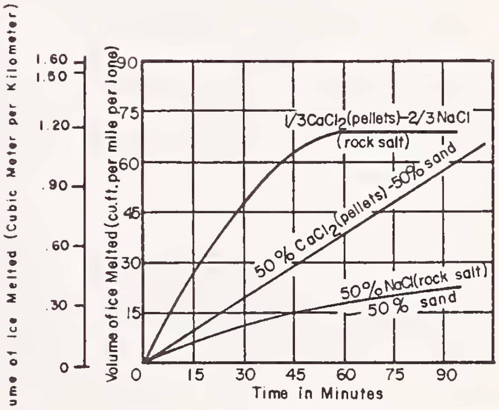


FIGURE 63: RATE OF ICE REMOVAL BY ABRASIVE - CHLORIDE MIXTURE AND CaCL2-NaCL MIXTURE AT -12.2° C (10° F) (62)

may be significant but should not be interpreted as exact expressions.

A three part laboratory study of various salt mixtures [4] consisted of certain measurements of the melting caused by application of salts to ice, with variables such as mixture composition, temperature, and dosage rate. The second part of the investigation was the attempt to devise testing procedures which give consideration to the weakening of the bond between an ice sheet and a portland cement or asphaltic concrete surface, and also to the effect of the wheel action of traffic. These two parts constituted the laboratory studies. The third part of the study was the intended field observations and correlation with the laboratory results.

These tests provided the following general results: (1) the quantity of melting was independent of the ice thickness; (2) the amount of melting varied directly with the quantity of the salt added; (3) the amount of melting varied with the amount of calcium chloride in sodium-calcium chloride mixtures; (4) the amount of melting in a given time was greater at higher temperatures; and (5) with calcium chloride the rate of melting was initially rapid with a subsequent slow-down, and with sodium chloride the rate was initially slow with a later speed-up, so that a time might be reached when the rate with sodium chloride equalled or became greater than that with calcium chloride; the exact comparison was dependent on the temperature.

Some attempts were also made to measure penetration rates of the crystals or pellets of the different salts. These tests, however, involved certain difficulties and the results were rather meager. It was thought that rate of penetration might have some bearing on ice removed on a road, but that this effect, if present, should be a factor which would affect the results in the drop tests and wheel tests described later.

A "drop test" (4) was used to indicate bond between the ice layer and road surface. Several distinct trends were noted from this series of tests. Among these: (1) the time of drop increases appreciably with decreasing temperature; (2) sodium chloride has a much longer drop time than the various mixtures at the lower temperatures but this difference becomes less at temperatures near the freezing point; and (3) the mixtures do not seem to affect the time of drop in any way except in direction proportion to the quantity of each chemical.

At the University of Minnesota, as reported by Kersten, et al. [4] tests were run on the amount of ice melted in fifteen to twenty minutes at varying temperatures. These tests confirmed the faster ice-melting action of calcium chloride at all temperatures and the greatly reduced effectiveness of salt at lower temperatures.

Field studies in Michigan showed that there was an average increase of 63 percent in clear area on icy pavements two hours after applications of a mixture of 67 percent salt and 33 percent calcium chloride mixture. Indications are that at a shorter time interval, mixtures would be more effective even at the high temperatures encountered -3.9°C to -5.6°C (25°F to 31°F) where salt normally does its best job. With lower temperatures and other factors entering in, the greater effectiveness of calcium chloride-salt mixtures would undoubtedly be more pronounced [4].

Winchester, Massachusetts bases it's use of sodium chloride on the three T's - terrain, traffic and temperature [63]. The average storm in this area has been a ten-hour storm with a 10.9 cm (4.3 inch) accumulation. A cost analysis for the typical storm for each of the three methods of 1) all salt program, no plowing; 2) sand-salt mixture and plowing; and 3) plowing and salting at the storms end was tried. The results showed method 1) as $7,014.70/storm, 2) $12,776.50/storm, and 3) $11,121.65/storm.

Through the melting action of salt, concentrated brine forms and resists further dilution under subfreezing temperatures. The strong brine quickly crystalizes. In contrast, a small amount of liquid-form calcium chloride added to 907 kilograms (a ton) of salt dilutes both chloride brines, bringing them to a state incapable of further melting. As a result, only a minimum of salt recrystalization occurs. Engineers report that application rates of salt per kilometer (mile) have been sharply reduced, while superior effectiveness has been achieved [64].

A field test was performed in January, 1969, on a county road in Clayton County, Iowa. Nine hundred and seven kilograms (one ton) of salt treated with 36 liters (9 1/2 gallons) of 32 percent calcium chloride solution was distributed over the full 6.7 meter (22 foot) pavement width at the rate of 140 kg per kilometer (500 pounds per mile). Surface conditions indicated 2 centimeters (3/4 inches) of accumulated ice from intermittent rain and snow. Temperature was estimated at zero degrees with a high for the day of -15°C (5°F). Wind was estimated at 29 kilometers per hour (18 mph), the sun was shining, and no traffic. When the spreading operation was completed, a return to the starting point showed a 100 percent slush condition, with no bonding of ice to the pavement. Elapsed time was 35-40 minutes [64].

As reported in [65] on the use of sodium chloride and calcium chloride is the deicing effectiveness of a mixture of these two materials, particularly at any temperature from about -23°C (-10°F) and up, mixtures of these deicers are more effective than either one used alone.

Sodium chloride is more generally available and has more of what industry calls "source points" relatively close to locations where it's to be used. Calcium chloride generally costs more to ship and takes longer to deliver.

In some localities, calcium chloride is used in practically every deicer application - as an advantageous ingredient in a mixture with sodium chloride. Because one application of such a mixture does a faster and more thorough job of deicing than "rock salt" alone:

- It takes fewer passes of spreader trucks and plows to get streets and highways clear - so theoverall costs of labor, equipment rental or equipment wear-and-tear are reduced.

- The total amount of deicer chemicals put down as a mixture is less than the total amount needed to achieve the same result with "rock salt" alone - so the amount of material that could affect the environment is less.

The cost factors have some secondary aspects. Because calcium chloride is more costly on a per-ton basis, and because it is more hygroscopic than sodium chloride, it gets more protection from those who buy it and put it in storage.

Instead of the open storage piles commonly employed for "rock salt" deicer reserves, calcium chloride generally goes into covered stroage with additional effort made to keep the stockpile moisture-proof.

The Michigan State Highway Department [66] made a comparison of sodium chloride and a 3:1 mixture of sodium chloride and calcium chloride.

The treatments were evaluated in sixty-seven storm conditions duirng January and Febraury 1f 1962. All application and handling methods followed normal winter ice control procedures. From these tests it was felt enough significant data were obtained to support the following conclusions:

(1) There was no appreciable difference between the effectiveness of plain salt and the mixtures at temperatures from -14°C to 0°C (6°F to 32°F).

(2) The mixtures did not store or handle as well as rock salt and there was some inconvencience and loss of material due to hardening.

(3) Both forms of the mixture performed in about the same manner.

(4) Straight salt, being cheaper, easier to store, and as effective as the 3:1 mixture, should continue as the Department's primary ice control chemical.

To obtain faster melting at temperatures below -9°C (15°F), a substantial increase in the amount od calcium chloride appears necessary.

During the past several years, rock salt has been the most widely used chemical for removing ice and snow from highway pavements during winter maintenance operations. In addition to generally being the most economical chemcial available for this purpose, rock salt usually can be handled and stored with less difficulty than other ice control materials, and generally its performance is satisfactory within normal storm temperature ranges. At lower temperatures, say -9°C (15°F) or below, calcium chloride is often used either alone or in combination with rock salt to increase the rate of melting.

Hank Farrell in Pennsylvania [67] has experimented with pre-mix deicers consisting of one part calcium chloride and five parts sodium chloride in an effort to combat ice and snow under unusually cold conditions where the temperature falls below -15°C (5°F).

If salt and calcium chloride are mixed, Pennsylvania suggests the following formula: For temperatures above 25 degrees F (-4°C) we use straight salt. With tempeatures between 15 degress and 25 degrees (-9 and -40°C) one part calcium chloride to three parts salt. For temperatures between 5 and 15 degrees F (-15 and -9°C) one part calcium chloride to two parts salt. For temperatures below 5 degrees F (-15°C) equal parts calcium chloride and salt. Below 5 degrees F (-15°C) only calcium chloride; however, Pennsylvania must rely on other anti-skid material available.

Caution should be exercised in the use of chemicals during periods of sharp temperature drops because slush and brine may refreeze. When the snow has stopped all slush should be plowed promptly so the pavement may dry as quick as possible.

Dow Chemical Company reported [68] that the most effective, economical and efficient deicer is a mixture of calcium chloride and rock salt. Thereasoning given is as follows:

- The most effective is calcium chloride. At all subfreezing temperatures normally occurring in snowbelt regions (chemically, down to -51°C (-59°F) practically, down to about -29°C (-20°F)) where speed of action is a significant factor, calcium chloride is more effective in a shorter time. Sodium chloride (chemically ineffective below -21°C (-6°F) rapidly loses effectiveness as subfreezing temperatures drop. Sluggishness is particularly noticeable beginning at about minus four degrees C (25° F).

- The most economical is rock salt. At elevated temperatures (-40C to 0°C or 25°F to 32°F) and where time is not a significant factor, rock salt is most economical. Its mode of occurrence and physical properties (essentially non-hygroscopic and non-deliquescent) give it an advantage in production and handling costs over manufactured products like calcium chloride which is highly hygroscopic and deliquescent.

- The most efficient are mixtures of calcium chloride and rock salt. Performance capabilities are directly proportional to the mixture ratios. The higher the $CaCl_2$ content, the better the performance of the mixture.

Thus, a mixture containing 100 percent calcium chloride and zero percent rock salt is the most effective and a mixture containing zero percent calcium chloride and 100 percent rock salt is the most economical (if speed of action and temperature conditions are not to be considered).

A mixture containing some calcium chloride and some rock salt is the most efficient provided their performance capabilities are respected.

Inasmuch as a pellet-type calcium chloride particle has its potency concentrated into the most effective (sphere-like) contact cofiguration, it will penetrate ice to a greater depth than a flake-type particle of equal calcium chloride concentration. The resultant liquid solutions will continue to work until they have equilibrated with surroundings.

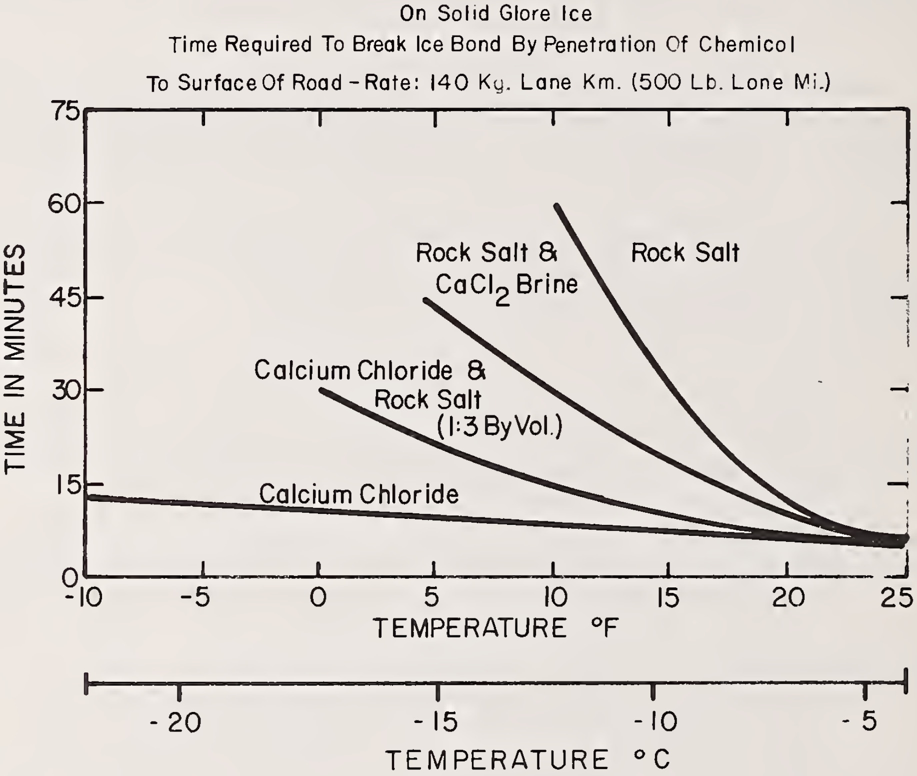


FIGURE 64: ICE PENETRATION AS RELATED TO PRODUCT COMBINATION

From a physical standpoint, wetness provided by solutions (liquids) or solids) of calcium chloride does cause rock salt to embed most quickly in an icy surface. This triggers rock salt's ice melting action and keeps the mixture within the treatment area.

A liquid solution of calcium chloride will initiate melting action slightly faster than its solid solution. But, because it contains less $CaCl_2$, it will use up its "melting power" and equilibrate with surroundings earlier [68].

In addition to application of salt(s) in rock or pellet form is to pre-wet the salt(s) and then apply.

Field tests that Iowa conducted during the winter of 1970-71 with 35 liquid calcium chloride applicator kits [4] showed that prewetting salt prior to application on the road produced:

1) Quicker snow melting because the 30-to 45-minute period usually required for brine to form was nearly eliminated.

2) Less salt waste because prewetted salt does not bounce on ice or snow but adheres and immediately begins to bore through the frozen layer.

3) Greater latitude in use of rock salt; melting has been experienced with prewetted salt at temperatures as low as -16°C (3°F) whereas normal salting is terminated when temperatures drop below -7°C (20°F).

4) Reduction in salt use because of the quicker, more effective use of the material. It is estimated that prewetting may reduce the quantity of salt required by 40 percent.

5) Greater periods of bare pavement surfaces during winter snow and ice storms.

Approximately 38 liters of liquid was applied to a metric ton of salt (10 gallons liquid to 2,000 lbs salt). On those trucks equipped with tail-gate spreaders, liquid calcium chloride was sprayed on the load at the yard by means of a multi-nozzle spray bath.

Connecticut is using propylene glycol for wetting salt on a road passing close to a reservior [4]. Other materials (salt brine, methanol) have been used by some agencies for prewetting salt.

In order to verify savings in salt usage and to determine to what degree the accelerated action of the salt is advantageous, test were conducted throughout the state of Michigan in the 1972-73 season. Of particular interest was the testing of prewet salt during the summer of 1972. From the results of these tests, Michigan's Department of State Highway's Maintenance Methods Unit made recommendations for continued testing of prewet salt [69].

During the fall of 1972, eight snow removal units at various locations thorughout Michigan, were equipped to spread ice control salt prewetted with a liquid chloride solution. Each unit was assigned a designated route so that results could be observed by area and district personnel. The use of two units, one at Coloma and another at Grand Ledge, was limited to the breakdown of trucks.

From the six remaining locations, 40 reports were received by the Methods Unit. The following is a general summary of these reports:

- 53% felt the wet salt worked better.
- 49% noted accelerated action.
- 40% stated that the wet salt sections were cleared earlier.
- 30% could see an improved pattern.

Other points noted:

- At temperatures of -3°C to 0°C (27°F to 32°F) there is very little difference in the melting action between wet salt and dry salt.

- The improved pattern of wet salt is evident at any temperature.

- At temperatures below 7°C (20°F) there are definite advantages in the accelerated action and the over-all results.

The reports on the testing conducted during the summer of 1972 indicate that by adding liquid, salt patterns are improved. The test was made over 1,050 meters (.2 mile). Salt sweepers went out and came back with the results. The dry salt spreads (scatter) out farther as contrasted to prewetted salt that stays more nearly where it is placed (in the center of the road). In addition, only four percent of the prewetted salt went off the pavement as compared to 30 percent of the dry.

The above facts were also noted on several reports observed during the winter testing. Thirty percent of received reports were from observations made at temperatures below 6°C (20°F). In each case, the observer felt that the wet salt was a definite advantage at the lower temperatures.

Characteristics of deicing chemicals other than the chlorides on their mixtures have been summarized by Zenowitz [46] as the following: Formamide has a comparatively high freezing point, 2.55°C (36.5° F) which is a disadvantage. However, this can be remedied by mixing with water which acts as a freezing point depressant in the mixture. A concentration range of about 33 to 88 percent formamide will not freeze at -18°C (0°F). A lower or higher concentration of formamide at this temperature (-18°C) will cause crystallization of ice or formamide to form a slush. Such crystallization and slush formation will continue at -18°C until a formamide concentration of either 33 or 88 percent is attained. Lowering the temperature produces further crystallization and change in formamide concentration in the remaining solution until the eutectic temperature, -48°C (-54°F) is reached. At the eutectic, no further change in concentration occurs, and the slush freezes to a solid [70]. It is good practice to use an 88 percent aqueous formamide solution although there is some loss of effectiveness of the formamide when used in this manner. It has also been found that the effectiveness of formamide is preserved by adding water-soluble freezing point depressants other than water.

Formamide is non-corrosive as compared to sodium or calcium chloride, but is about ten to fifteen times as expensive. When applied to a pavement, it is relatively non-slippery; i.e., a slipperiness equal to that of a wet pavement [70]. It is non-toxic unless biodegraded into toxic products which may be dangerous to aquatic life [7] and [72].

Formamide or a mixture of formamide and water are liquid deicers which can serve effectively in automatic ice prevention systems triggered by temperature sensors.

Urea is a chemical deicing alternative which is being used to a large extent. Urea in pellet or liquid form is being used satisfactorily for deicing by approximately 25 airports located in the snow and ice area [72]. The Severn Suspension Bridge and the associated Aust Viaduct and roadway joining England with Wales has been anti-iced with urea pellets since its opening ten years ago [74]. It has been reported [71] that prilled (pelletized) urea was found to perform better than liquid chemicals at temperatures from -9 to 0°C (15 to 32°F). However, below -9°C (15°F) the liquid chemicals, formamide or glycol formulations were found to be more effective. It has been used in recent years on grids of bridges in the District of Columbia because it is non-corrosive and non-conductive and provides satisfactory deicing.

Urea is less effective than salt. About 1-1/2 to 2 times as much material is required and it is five to ten times more costly than salt [75], [76], and [77]. The eutectic temperature of a water solution of urea is -11.7°C (11.0°F). A 32.8 percent concentration of urea is required at the eutectic [76]. Two grams of urea in 100 grams of water depresses the freezing point by 0.61°C (1.1°F), similar to the behavior of ethylene glycol, whereas sodium chloride at a similar concentration depresses the freezing point by 1.19°C (2.14°F) [77].

Urea and substituted urea compounds are not acutely toxic at concentrations of one milligram per liter or less (77). One report [71] presented findings of the Environmental Health Laboratory, Kelly AFB, Texas, that urea was toxic to aquatic life when more concentrated than 10,000 mg/l. The corresponding toxicity thresholds are 5000 mg/l for glycols and 500 mg/l for formamide base deicers [79] and [72]. The Kelly AFB Environmental Health Laboratory advances various recommendations concerning the handling of runoff waters containing urea or glycol deicers to offset biodegradation problems.

It is felt that urea is an acceptable chemical deicing candidate for temperatures above -9°C (15°F). However, either the runoff should be controlled or it should be used in areas where the danger of melt solutions of urea running into critical waterways is at a minimum.

In studies of fifteen alternative deicing chemicals to chloride deicers [85], [80], and [81], California Department of Transportation researchers decided that only two, sodium formate and tetrapotassium pyrophosphate (TKPP), were reasonably effective alternative deicing chemicals without any greater toxic or harmful ecological effects than sodium chloride. As sodium formate caused portland cement concrete (PCC) to deteriorate and TKPP did not, the latter was chosen for field trials and recommended for use on decks of bridges located in areas where the temperature rarely drops below -4°C (25°F). The researchers reported that frictional properties comparable to those obtained for water-treated pavement surfaces were obtained when a 30 percent solution of TKPP was applied at a rate of 50 grams per square meter (0.01 pounds per square foot) to the surface of a PCC or an asphalt mix overlaid bridge deck. TKPP is reported as not being able to penetrate through the concrete to affect any reinforcing steel, although it has a corrosive effect on vehicluar steel. It is mixed with two percent lime to reduce its corrosive effect on exposed steel. A residual effect of several days has been experienced in field trials of TKPP. The only drawbacks for the material, other than its corrosiveness to exposed steel, are its price, approximately fifteen times that of salt, and the relatively high temperature, -4°C (25°F), below which it is ineffective.

TKPP is an alternative deicing chemical that merits consideration for use in the prevention of frost in critical highway locations situated in areas which experience mild winter weather.

A mixture of 75 percent formamide, twenty percent urea and five percent water [70], is considered a promising alternative to chloride deicing at low temperatures because it out-performs salt at very low-temperatures, is considerably less corrosive, and it non-toxic if not biodegradable. It is cheaper than formamide but costs approximately ten times as much as sodium chloride. Hearst [70] considers this mixture to be the best material found for melting ice on airport runways at temperatures from the freezing point of water to below -18°C (0°F). It is effective at still lower temperatures if a certain amount of slush formation can be tolerated and if it is applied at temperatures no lower than -18°C (0°F). This liquid deicing mixture can be used effectively in automatic ice prevention systems triggered by temperature sensing devices.

A pelletized mixture of 75 percent tripotassium phosphate and 25 percent formamide has been recommended for deicing use [82]. This mixture is recommended as an alternative to sodium chloride because it can be applied with existing equipment used for salting and sanding. It has been reported [88] to melt ice at -23.3°C (-10°F) and is effective at lower temperatures, but at a reduced rate. Although its corrosive effects are considered acceptable, some minor scaling of concrete may result. It is non-toxic, but may promote vegetation growth. The cost of manufacture is claimed to be moderate (estimated at ten to fifteen times greater than that of sodium chloride) and the recommended rate of application is .5 to 1 kilogram per square meter (1/8 to 1/4 pounds per square foot) of ice surface. Harris et. al. [82] believes that this mixture can serve effectively as a deicing material at low temperatures.

The following alternative deicing chemicals are not recommended for consideration because of the undesirable characteristics noted: Ammonium acetate: This material is slightly corrosive to metals like copper and aluminum. Its hygroscopic characteristics make application of the material difficult [70].

Ammonium nitrate: This material is extremely aggresive to steel and damaging to concrete [75] and [76].

Ammonium sulfate: This material reacts with lime in concrete to cause deterioration and cracking of concrete. It damages even high quality air entrained concrete [75] and [76]. Although its eutectic temperature is at about -18.9°C (-2°F).

Alcohols: These materials pose a fire hazard and have a limited reaction time because of relatively quick evaporation [75] and [76].

Glycols: The glycols are water-white, almost odorless, high boiling, hygroscopic liquids. Ethylene glycol, the lowest molecular weight member of the family, is best known as the base of "All Winter" or "High Boiling" automotive antifreeze. The desirable properties of ethylene glycol-water solutions have resulted in their wide-spread industrial use as heat transfer fluids at both elevated and sub-freezing temperatures. Propylene glycol is relatively nontoxic and allowed for internal consumption in small amounts, therefore, finding use in the food processing industries. Their hygroscopicity and the low freezing points of their water mixtures makes ethylene and propylene glycol ideally suited for use in low temperature air handling systems. The glycols serve in a host of applications in the petroleum, natural gas, chemical, food processing, brewing and refrigeration industries. Their use in snow melting systems, hot water heating, chilled water cooling and air tempering coil applications are well known [83]. It should be noted that while ethylene glycol itself freezes at -12.8°C (+9°F), a 65 percent glycol water solution remains fluid at 53.9°C (-65°F). In solutions containing up to 58 percent glycol, small individual ice crystals separate on cooling; thus forming a non-rigid slush.

These chemicals create a slippery pavement surface and leave a residue which is hard to removed [83]. They tend to wash off and their run-off causes problems [99]. They are very expensive and their availability is subject to curtailment by fossil fuel conservation. New York reported [99] that they have done considerable research into the glycol type or product and find they are quite effective, though expensive. On the basis of experimentation with a formamide-based material and propylene glycol over a three year period, Minsk concludes: (1) Liquid deicers lend themselves to automated application, (2) They have a residual action, (3) They are effective at low temperature, (4) They are relatively nonpolluting, (5) They are expensive, costing from $110 to $330 per metric ton ($100 to $300 per ton) which figures out to be $1.61 per square hundred meters or $1.50 per 1,000 square feet per application, and (6) Automated distribution systems are initially expensive.

Sodium formate: This material unduly damages concrete [85].

Ammonium carbonate: This material reacts with copper and copper alloys [70].

Although several effective alternative chemicals to chlorides are available for highway deicing, they are costly. The least expensive alternative chemical, urea, costs from six to ten times more than sodium chloride. When the cost of the others, which may run from ten to 40 times that of sodium chloride are considered, the reluctance of maintenance groups representing State highway agencies to try alternative chemicals is understandable, considering that they operate on restricted budgets. This suggests that the problem may not be one of obtaining alternatives but one of obtaining noncost prohibitive alternatives.

A source for less expensive alternative chemical deicers may be municipal waste (garbage) which has critical disposal problems at the present. The following speculative approach for obtaining cheaper but effective chemical deicers from waste is suggested both in the interest of promoting the utilization of waste material and of developing alternative chemical deicers or other nonchemical deicing alternatives.

A speculative approach has been suggested for hydrolysates of proteinaceous waste for feasibility consideration. If feasible, it could result in the utilization of part (ten to twenty percent) of the municipal wastes and could supply a relatively economical deicing mixture usable as an alternative to chloride deicing [70]. It is suggested that the proteinaceous part of the heavy fraction of municipal waste (garbage) be hydrolyzed and the water soluble hydrolysate be concentrated or dried by evaporation. The method could be feasible if the residue thus obtained consists for the most part of the amino acids and simple peptides. If sufficient quantities of such low-molecular weight, water-soluble, pH - neutral compounds are present, this residue or concentrated solution could then be used for deicing.

A survey report [77] recommended a search for hydrophobic substances which can be used to reduce the adhesion of ice on pavements, as this approach was potentially the most valuable of the alternatives to chloride deicing.

Among some of the materials suggested in the literature [86], [87] and [88] as potential hydrophobic deicing coatings on films are:

- Fatty-quaternary - ammonium compounds like a) dimethyl-tallow-ammonium chloride ("Aliquet H-266" made by General Mills, Inc.); b) dimethyl-tallow-ammonium chloride and alkyl-imidizoline derivative ("Arosurf FA-100" and "Cationic Softner - X" made by Onyx Chemical Co.); c) fatty amide derivative ("Ceramine HC" made by Sandoz Colors and Chemicals) and d) quaternary methylol amide ("Hipochem Aquapruf" made by High Point Chemical Corporation) [29].

- Organo-fluorochemical compounds like a)"Scotchgard", a soil repellant made by 3M; b) pyridinium fatty water repellant containing a flourocarbon ("Wuarpel" developed by U.S. Army Quartermaster CORPS for textiles [86] and [87].

- Organo-silicone compounds like a) siloxane resins; b) silicones made by Dow Corning and G. E. Silicone Products Department [86] and [87].

- Polymers like polyethylene with surface films of stearamide, oleamide, palmeatamide and myrestamide [86] and [87].

- Plastics like polyethylene, Kel-f, Teflon, silicones [86] and [87].

- Coatings of 0.1 to ten percent aminoborane, alkali metal borohydride, or alkali metals with borohydrides [88].

Such materials have been developed and used to repel water on surfaces of materials other than highway pavements. However, they are presented as examples of materials thay may be feasible for highway pavement deicing. According to a report [86], Dr. Anthony E. Lintner, a chemical engineer and specialist in surfactants, believes that it should be possible to develop a substance that would reduce the adherence of ice on pavements.

At the present time, a study of the toxicity and performance of a number of there aforementioned materials together with other materials including paints is being carried out by the Environmental Protection Agency in its research laboratory in Edison, New Jersey and through other contract research. A forthcoming report should furnish information as to the feasibility of using the various water-repellent films for control of highway icing. Also, a research study sponsored by the Environmental Protection Agency, being conducted by Ball Engineers in Boulder, Colorado is in the process of conducting field experimentation with promising hydrophobic materials. A report due in the near future should outline the feasibility and guidelines for hydrophobic materials that survive field evaluation. Before these materials become implementable on a wide scale, work is required to identify application rates, frequency of application and economical means of producing the materials.

Potassium chloride is a poor substitute for sodium chloride because it has a higher eutectic temperature and is approximately triple the cost [101].

UCAR-II [89] is used for deicing aircraft and has an initial freezing point of -37°C (-35°F) at 50 percent dilution. It is excellent as noncorrosive material for aluminum; mild steel and magnesium. However, this has been too expensive to be considered as an alternative to the more commonly used deicers on highways.

Abrasives

Abrasives are applied on snow or ice covered pavements to obtain a higher coefficient of friction for the automobile tires. Since abrasives are usually easily noticed after having been applied, they also serve to enhance public relations in that efforts are being undertaken to combat the snow and ice problems.

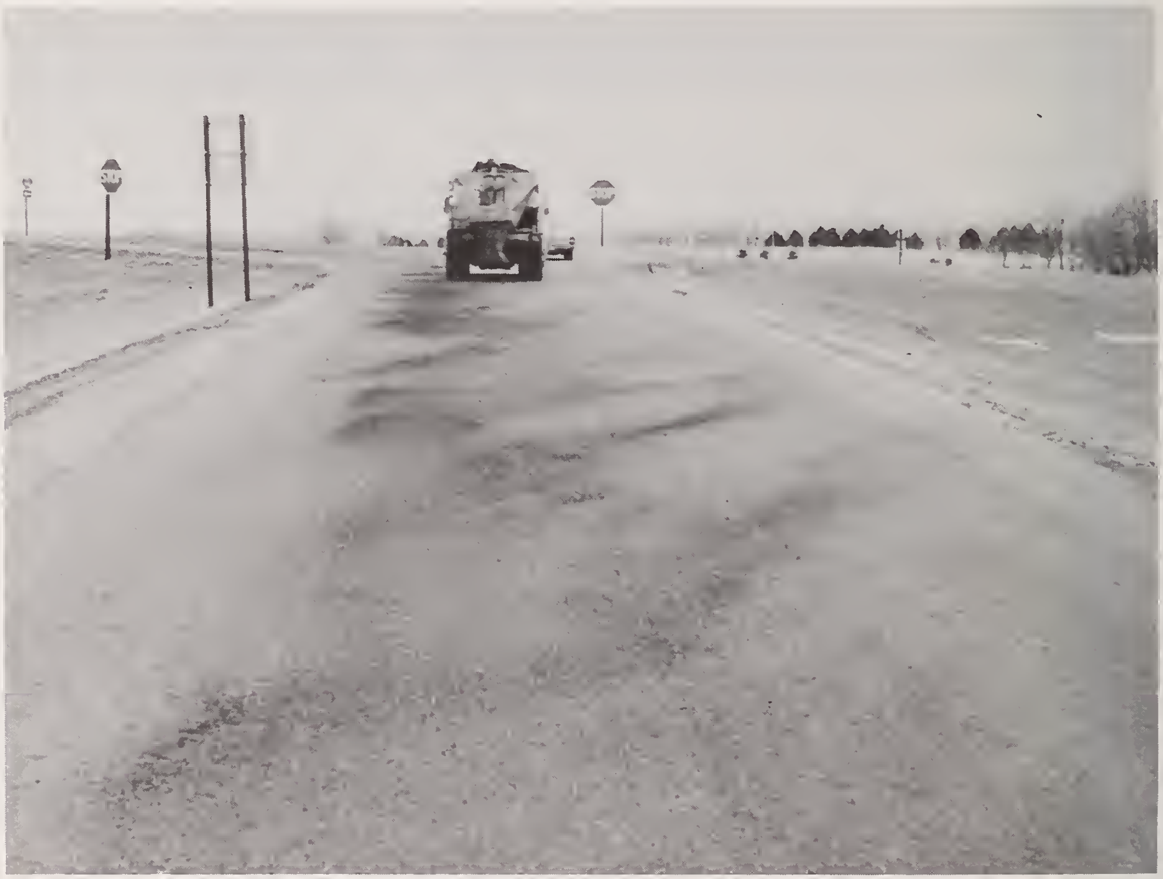


FIGURE 65 SOUTH DAKOTA SANDER SPREADING SAND - SALT MIXED MATERIAL ON AN ICY INTERSTATE RAMP (Courtesy South Dakota Department Of Transportation)

The source for abrasives is very divergent; sand from sand bars, quarries, left over from construction or crushed aggregates; slag; boiler house cinders, coke cinders and stone.

The performance [46] and [4] of four types of antiskid materials (boiler-house cinders, coke cinders, sand, and stone) was evaluated on a laboratory circular track, and little difference was found in their effect on the coefficient of friction [90]. It was found that material passing the .300 mm (No. 50) sieve made no contribution to increasing the coefficient of friction. However, these materials exhibited considerable differences in retention of premix calcium chloride.

In 1968, the National Safety Council evaluated the relative effectiveness of salt and various abrasive materials in increasing the skid resistance of a glare ice surface shortly after the materials were applied.

Evaluation of the frictional effectiveness of salt, sand and cinder spreads was made on a special ice course adjacent to the airport but remote to the major test courses. This was believed to be essential in order that there be no contamination of the major test course. All tests were performed by the General Motors skid trailer, using the conventional highway tread tires with which it was equipped.

Since destruction of, or at least major damage to, the test course was inherent in these tests, a large number of replications could not be made. Two sets of tests were conducted before the course was destroyed. One was run during a period when the ambient air tempeature ranged from -8.9°C to -33°C (16°F to 26°F), averaging approximately 6.7°C (20°F), and the ice surface tempeature ranged from -10°C to -0.6°C (14°F to 31°F), averaging approximately 06.1°C (21°F) [91]. In the second series of tests the ambient tempeature remained very close to 0°C (32°F) as did the ice surface temperature. The results of these two series of tests are shown in Table 17. As shown in this Table, the sand and cinders were applied only at the rate of .71 cubic meters per two lane kilometer (1-1/2 cubic yards per two-lane mile) and were only tested immediately after application. The two gradations of rock salt, one a conventional coarse crushed gradation and the other a mixture containing 75 percent coarse crushed and 25 percent fine crushed, were applied both at the rate of 200 kilograms per two-lane kilometer (700 lbs per 2-lane mi.) and at the .71 cubic meters per two-lane kilometer (1-1/2 cu. yds. per 2-lane mi.); and were tested immediately after application and subsequently after the passage of 15, 30 and 60 minutes.

Whenever either the coarse crushed or the mixture of coarse and fine crushed rock salt was applied at the same rate as the sand and cinders the resulting coefficient immediately after application was in the order of or greater than the coefficient of the sand spread. When coarse crushed rock salt was used at this rate of application,

TABLE 17: SKID TRAILER COEFFICIENTS ON SPREADS OF SAND, CINDERS, AND ROCK SALT [91]

FIRST RUN					SECOND RUN				
TIME IN MINUTES	ICE TEMPERATURE		COEFFICIENT OF FRICTION OF TREATED SURFACES	BARE ICE COEFFICIENT	TIME IN MINUTES	ICE TEMPERATURE		COEFFICIENT OF FRICTION OF TREATED SURFACES	BARE ICE COEFFICIENT
	DEGREE C	DEGREE F				DEGREE C	DEGREE F		
SAND APPLIED AT A RATE OF .71 CUBIC METERS PER TWO LANE KILOMETER (1.5 CUBIC YARDS PER TWO LANE MILE)									
0	- 10.0	14	0.109	0.071	0	0	32	0.098	0.069
CINDERS APPLIED AT A RATE OF .71 CUBIC METERS PER TWO LANE KILOMETER (1.5 CUBIC YARDS PER TWO LANE MILE)									
0	- 9.2	15.5	0.128	0.069	0	0	32	0.120	0.069
COARSE CRUSHED ROCK SALT APPLIED AT A RATE OF 200 KILOGRAMS PER TWO LANE KILOMETER (700 POUNDS PER TWO LANE MILE)									
0	- 8.9	16	0.085	0.069	0	0	32	0.105	0.069
15	- 7.8	18	0.068	0.069	15	0	32	0.100	0.069
30	- 7.2	19	0.079	0.064	30	0	32	0.106	0.069
60	- 6.1	21	0.079	0.064	60	0	32	0.112	0.069
COARSE CRUSHED ROCK SALT APPLIED AT A RATE OF .71 CUBIC METERS PER TWO LANE KILOMETER (1.5 CUBIC YARDS PER TWO LANE MILE)									
0	- 8.1	17.5	0.118	0.069	0	0	32	0.120	0.069
15	- 7.2	19	0.073	0.069	15	0	32	0.112	0.069
30	- 7.2	19	0.079	0.069	30	0	32	0.112	0.069
60	- 5.6	22	0.079	0.064	60	0	32	0.106	0.069
MIXTURE OF 25 PERCENT FINE CRUSHED, 75 PERCENT COARSE CRUSHED ROCK SALT APPLIED AT A RATE OF 200 KILOGRAMS PER TWO LANE KILOMETER (700 POUNDS PER TWO LANE MILE)									
0	- 4.2	24.5	0.079	0.064	0	0	32	0.107	0.069
15	- 3.9	25	0.073	0.064	15	0	32	0.106	0.069
30	- 2.8	27	0.079	0.064	30	0	32	0.102	0.069
60	- 1.1	30	0.073	0.064	60	0	32	0.106	0.069
MIXTURE OF 25 PERCENT FINE CRUSHED, 75 PERCENT COARSE CRUSHED ROCK SALT APPLIED AT A RATE OF .71 CUBIC METERS PER TWO LANE KILOMETER (1.5 CUBIC YARDS PER TWO LANE MILE)									
0	- 3.9	25	0.103	0.064	0	0	32	0.112	0.069
15	- 2.2	28	0.097	0.064	15	0	32	0.106	0.069
30	- 2.2	28	0.095	0.064	30	0	32	0.106	0.069
60	- 0.6	31	0.105	0.064	60	0	32	0.105	0.069

the coefficient immediately after application was near or equal to that of cinders. When the salt spreads were made at the rate of 200 kilograms per two-lane kilometer (700 lbs. per 2-lane mi.) and an air tempeature of 0°C (32°F), the coefficient immediately after application was somewhat greater than that of sand spread at the conventional rate but somewhat below that of cinders.

When similar spreads were made at an air temperature of 6.7°C (20°F) and an ice temperature of -6.1°C (21°F), neither application of salt at the 200 kilogram rate resulted in a coefficient equal to that of sand at a .71 cubic meter rate.

The general tendency for both application rates at either temperature at which these tests were performed was for the coefficient of friction of the salt spread to be reduced the first fifteen minutes after the spread was laid and then to increase somewhat as time increased to sixty minutes. In most cases, however the coefficient of the salt spread after sixty minutes has lapsed was somewhat lower than that immediately after application.

In general the mixture of coarse and fine crushed rock salt appears to result in approximately the same coefficient of friction at the same application rate as does the coarse crushed rock salt alone, with perhaps some advantage to the mixture at lower ice temperatures. However there is some evidence that the loss in coefficient of the spread containing the mixture is less as time progresses than that of the spread containing coarse crushed rock salt alone.

Care must be exercised when choosing aggregate sizes as a deicing abrasive. If the material size is too large there is potential for damaging windshields and if the partical sizes are too small, wind may whip the abrasives off the roadway in addition to enhancing their freeze potential while in storage. A large percentage of the abrasive passing a 4.75 mm (No. 4) sieve will act to enhance slipperiness rather than serve its purpose as an abrasive. The selection of abrasives should be based on availability, frictional coefficient gradation and cost.

New York Department of Transportation specifies for abrasvies that; the maximum size of particle should pass a 9.50 mm (3/8 inch) sieve, and there should be preferably less than five percent passing the # 200 (75 micrometer) sieve, particularly in the case of artificial sand [92]. Particles larger than 9.50 mm (3/8 inch) could damage passing vehicles. Particles finer than .300 mm (No. 50) are of little use in increasing the coefficient of friction, and will retain moisture and freeze. The fines in artificial sand are particularly undesirable due to their muddy or lubricating effect.

Illinois Department of Transportation has specified [93] that sand for ice control should be clean, hard, sharp, free from loam clay or frozen lumps, with 100 percent passing a 9.50 mm (3/8 inch) sieve, not less than 45 percent passing a 1.18 mm (No. 16) sieve and not more than 30 percent passing a .300 mm (No. 50) sieve. If this gradation is not avaiable, any available gradation may be used in an emergency.

Cinders are sharper than sand, cling to tires, and cut into ice or packed snow better. They should be used in preference to any other abrasive. The melting or embedding action of cinders with their greater porosity is better than sand because of the larger quantity of moisture and chloride held at or near the surface of the cinder particles. Due to their dark color, cinders absorb more heat than other materials when the sun is shining. Also, cinders have less tendency to clog drainage structures.

Stone screening with fines removed by washing produce a good abrasive, the gradation of these should be the same as for sand. Illinois also specifies the treatment of abrasives for storage as:

- When abrasives are placed in storage, they should be treated with either dry calcium or sodium chloride (rock salt) or a mixture of the two; the quantity depends upon the moisture content of the abrasives. This should be uniformly mixed with the abrasives to properly protect the abrasives from freezing before application, to aid in anchoring the material in the ice or packed snow, and to prevent wind or heavy traffic from sweeping it off the surface.

- The chloride should be well mixed with the abrasive when it is placed in stockpiles or in bins. Equipment available determines the mixing methods; however, the desired methods are with belt conveyors or concrete mixers and end loaders.

Idaho [94] found the use of some basalt deposits for antiskid, intolerable due to the tire puncturing slivers produced from the crushing operation. Also, the soil fraction and the natural fines resulting from crushing (passing the .300 mm (No. 50) mesh sieve) is of little value to antiskid properties. The fraction below the .300 mm (No. 50) mesh sieve capable of retaining water is causing undue expense in removing from stockpile and also in feeding the material through spreaders due to freezing. The large rock particles are causing considerable glass breakage, to a great extent attributable to the high impact force of these particles when projected into a windshield by a rotating tire and the differential speeds of the vehicles. As a result of these problems, Idaho adopted a gradation requirement shown in Table 18 and requires that the moisture content be kept at three percent or less so the material will be free flowing at freezing temperatures.

The State of Washington specifies abrasives as [95] crushed or screened materials for sanding purposes generally, should at least

TABLE 18: ANTISKID GRADATION REQUIREMENT [94]

SIEVE SIZE		PERCENT PASSING
METRIC	STANDARD	
12.50 mm	1/2 inch	100
9.50 mm	3/8 inch	95 - 100
4.75 mm	No. 4	20 - 50
2.36 mm	No. 8	0 - 30
.300 mm	No. 50	0 - 10
.150 mm	No. 100	0 - 5

meet the specifications for "Maintenance Rock" as specified in their standard specifications or more usually a .64 cm (1/4 inch) minus material specified by the maintenance engineer. Care should be made in the use of quarry rock which breaks in slivers when crushed.

Depending upon local conditions, sanding abrasives may have up to 60 kilograms per cubic meter (100 lbs. of calcium chlorides per cubic yard) of abrasive added to them when placed in sand sheds or stockpiles to keep them from freezing.

Alternatives to Deicing Chemicals and Abrasives

In recent years, much attention has been focused on the necessity of removing snow and ice from freeways, highways, and expressways because these facilities must move vehicular traffic in large numbers, at high speeds, and with the greatest possible safety. Some points or areas in these roads do not lend themselves to the conventional means of clearing snow and ice by plowing and salting and, therefore, it is desirable that other methods be found [96].

The principal aim of any acceptable alternative to deicing chemicals should be the efficient disruption of the ice to pavement bond without involving a large drain of energy or damage to pavement structures. In general, mechanical equipment is usually not efficient in the removal of compacted snow or ice and is at time injurious to the pavement surface, curbs, medians, lane delineators, etc. Equipment included in the mechanical category are scrapers, chisels, rollers, crushers, disks, and air blasters blowing finely crushed abrasive materials, compressed air plow and brush, and blower systems. The general effect of the use of such mechanical equipment is to furnish a more suitable surface for the application of abrasives [46].

Disruption of the ice-pavement bond with ultrasonic or vibrational energy [97], [98], and [99] or electromagnetic energy [99] has been proposed. Theoretically, such approaches show promise but in practice they involve large energy losses and require considerable amounts of energy [86]. Further research of these approaches may develop more effective and practical application [46].

One of the more difficult determinations in the design of embedded heating systems in pavements is the calculation of the heat needed to prevent ice from forming or snow from accumulating. Designers must provide sufficient heat capacity for effective melting but not over-design the system and unnecessarily increase the cost of an already expensive operation [100].

Published information on procedures for calculating design heat requirements is limited and can be misleading. Some of the procedures are based on snow melting field tests during mild weather [101] and do not necessarily apply to systems operating under severe winter weather. The procedure recommended in the ASHRAE Guide and Data Book [103], the only comprehensive guideline believed to be available in North America, has proved to be of uncertain value. A comparison of calculated design heat loads, using ASHRAE procedures, with actual installed heat capacities for five cities in the northern United States [104] shows that the installed heat capacities are often quite different from the theoretical values, (Table 19). The information on installed capacities, shown for Canada, was obtained from unpublished reports and published literature [105] and [106]. Installed heat capacities are generally somewhat lower in Canada than those reported in the United States, a surprising development considering the more severe climatic conditions under which Canadian systems usually operate.

G. P. Williams in his work [100] attempted to assess methods of calculating design heat requirements of embedded snow melting systems, particularly those operating in cold climates. The study is based on an extensive review of the literature and on snow melting tests carried out on heated pavements, over three winter periods, on the grounds of the National Research Council, Ottawa, Canada. The paper is divided into three parts. The first deals with the problem of estimating surface heat losses from bare pavements during periods between snowfalls; the second, with surface heat loss duirng the immediately following snowstorms. Formulae developed from these observations are compared with those recommended by ASHRAE [103]. The third section is concerned with the problem of allowing for heat loss into the ground around and under heated pavements.

In concluding, he stated:

- The ASHRAE [103] formulae for calculating design heat requirements for now melting systems are reasonably satisfactory provided adjustments are made to take into account the size of the heated area, exposure to wind, and height at which wind speeds are measured.

TABLE 19: INSTALLED AND ASHRAE-CALCULATED HEAT REQUIREMENTS [100]

NORTHERN UNITED STATES	Spokane		Minneapolis - St. Paul		Detroit		Burlington		Hartford	
	m^2	Ft.^{2}	m^2	Ft.^{2}	m^2	Ft.^{2}	m^2	Ft.^{2}	m^2	Ft.^{2}
CLASS I (residential)										
Installed	321-428	30-40	449 -803	42-75	428-642	40-60	535	50	321	30
ASHRAE*	(385)	(36)	(278)	(26)	(300)	(28)	(396)	(37)	(503)	(47)
CLASS II (commercial)										
Installed	321-482	30-45	642-803	60-75	642	60	535	50	535	50
ASHRAE*	(556)	(52)	(685)	(64)	(610)	(57)	(621)	(58)	(1,113)	(104)
CLASS III (critical)										
Installed			749-803	70-75	642	60	(803)	75	749	70
ASHRAE*	(835)	(78)	(1,113)	(104)	(1,124)	(105)	(1070)	(100)	(1,145)	(107)

CANADA	British Columbia		Prairie Provinces		Southern Ontario		Ottawa - Montreal		Atlantic Provinces	
Range for	m^2	Ft.^{2}	m^2	Ft.^{2}	m^2	Ft.^{2}	m^2	Ft.^{2}	m^2	Ft.^{2}
Installed**	161-268	15-25	321-589	30-55	214-428	20-40	482-589	45-55	375-589	35-55

* Calculated; includes adjustment for ground heat loss
**ASHRAE calculations not available; no information on class of installation

- The limiting condition controlling design heat requirements of snow melting systems operating in cold climates is the maintenance of an ice-free surface immediately following snowstorms rather than effective melting of snow during a storm. These heat requirements can be estimated by calculating the rate of surface heat loss from bare, wet pavements using weather data obtained from representative or "design" storms.

- The use of insulation reduces edge and ground heat losses to insignificant amounts, eliminating the need to make allowances for such losses in design heat calculations for insulated snow melting systems.

From the APWA (American Public Works Association) [107] the following list summarizes the total heat energy necessary for a snow melting system:

- Raising the temperature of the snow or ice to the melting point (q_s). The temperture of falling snow or ice that has formed on the pavement is usually considered to be the same as the ambient air temperature.

- The heat of fusion of ice (q_m).

- Evaporation of some of the water formed in the melting process (q_e).

- Loss by radiation and convection (q_n).

- Loss by conduction to the ground (q_g).

This total heat requirement may be expressed as:

$$q_o = q_s + q_m + A_r (q_e + q_h) + q_g \tag{16}$$

A_r is the "free area ratio". The ratio of the surface area free of snow to the total surface area of the system. Evaporation, radiation and convection are a function of the area exposed to the atmosphere and wind action. If even a thin film of snow is allowed to accumulate on the slab there is no direct heat loss to the atmosphere and A_r is zero.

Evaluation of the energy needs requires knowledge of the meteorological conditions when a storm occurs, and an assumption as to the desirable operating conditions. Chapman, in 1952, derived equations for calculating the energy requirements of a snow melting system. He assumed that the system was operating before snow began to fall so that melting occurs at first contact and a water film is soon formed on the surface. So long as the surface can be maintained above the freezing point all subsequent melting occurs in this water film.

Noted in NCHRP #4, [108] the total heat required to keep highway pavements reasonably free of snow and ice is the sum of the heat required to (a) raise the temperature of the snow to the melting point and melt the snow, (b) provide for evaporation losses, (c) provide for convection losses at the surface, and (d) provide for heat losses downward. This can be expressed by:

$$Q_T = A_r(Q_m + Q_e + Q_h) + Q_s + Q_L \tag{17}$$

in which

Q_T = total heat requirement;

Q_m = heat required to melt snow;

Q_e = heat lost through evaporation;

Q_h = heat lost through convection;

Q_s = heat to raise the snow temperature to its melting point;

Q_L = heat losses downward.

The term A_r is as introduced by the American Public Works Association [108].

"Snow and Ice Removal from Pavements Using Stored Earth Energy" a report by the Federal Highway Administration [109] noted;

> Of the other energy sources studied, a snow removal and deicing system utilizing the stored energy in the earth beneath and adjacent to the roadway pavement appears to be technically feasible and furthermore has the least impact on the Nation's energy requirements. Simultaneously, it was recognized that the economics of such a system were critically dependent upon the volume of earth that had to be thermally coupled to each square foot of the pavement surface. This volume of earth, in turn, is dependent upon the efficiency of transporting and distributing the earth's thermal energy, the average temperature of the earth (related to the average annual environmental temperature), the nature and composition of the soil, the conductivity of the pavement, and on the total annual energy required to remove snow and deice pavement surfaces.

The use of large volumes of earth as an energy source is consistent with the ever increasing need to conserve the world's energy resources. Since the heat pipe is an essentially isothermal heat transfer device, it is possible to effectively utilize this low grade energy source.

The yearly average temperatures can be utilized in estimating the feasibility of an earth reservoir system for specific locations. At depths of 7-1/2 meters (25 feet) or greater, the average soil temperature approximates the yearly average ambient temperature. It was noted that the response of the soil temperature lags behind the ambient temperature. This means that the potential for heat transfer will not drop off sharply as the winter progresses.

In addition to temperature, other soil properties must be considered in evaluating the potential usefulness of the earth at a given location, as an energy source. The density, the percent moisture content, and the consistency all effect the thermal conductivity and the heat capacity of the soil. The thermal conductivity of soil increases with increasing density for a given moisture content and temperature. The thermal conductivity also increases with increasing moisture content for a given density and temperature. Temperature alone does not have a significant effect on the thermal conductivity of soil.

The thermal conductivity varies with the texture of soil. For a given density and moisture content, the conductivity is relatively high for coarse textured soils such as sand or gravel, somewhat lower for sand loam soils, and lowest for fine textured soils such as silt loam or clay. For example, for a dry density of 60 kilograms per cubic meter (100 pcf) and a moisture content of ten percent, the thermal conductivity of a sand soil is eleven BTU per square foot - hour - degree F - inch, (.23 cal per cm^2 - hour - degree C - cm) compared to seven BTU per square foot - hour-degree F., - inch (.14 cal per cm^2 - hour - degree C - cm) for a silt and clay soil. On the natural environment in the field, this order would not necessarily hold since finely textured soils ordinarily contain a higher moisture content than sandy soils.

In areas where earth heat pipes are used for pavement deicing, the earth heat contained in the volume of earth adjacent to the earth heat pipes is continually being pumped to the surface during the winter months. Here, it is used to melt snow and ice or is otherwise dissipated to the environment. To assure an adequate supply of earth heat for the next winter, this energy must be replenished during the summer months.

The test facility, located at the Fairbank Highway Research Station, is designed to investigate the variables associated with removing snow and ice from pavement surfaces by thermal methods [109]. The site is an outdoor open space, away from buildings, and covers an area of about 370 square meters (4000 sq. ft). There are three 3.65 by 7.32 meter (12 ft by 24 ft) concrete test slabs:

1) Unheated Control Slab
2) Electrically Heated Slab
3) Earth Heat Pipe Slab

All of the test slabs are nine inches thick following the trend in modern highway construction. The control slab is unheated and serves as a test control for the electrical and earth slabs. Both the electrical and earth slabs contain heat pipes charged with ammonia. In the electrical slab, each heat pipe terminates outside the slab in a short down leg. This is wrapped with an electrical heater which can be controlled at selected power levels from the instrumentation trailer. In the earth slab, each heat pipe extends beyond the slab boundaries and then into the earth to depths of either 9 or 12 meters (30 or 40 feet). All of the heat pipes run parallel to the 3.66 meter (12 ft) dimension and have a 3.18 centimeter (1.25 inch) cover of concrete over them.

Through application of the mathematical model (presented in reference 109) to the control slab and the electrical slab, it was possible to match predicted and actual temperature profiles and heat pipe temperatures as a function of time, for specific assumptions for the thermal losses, the ground heat inputs, pavement conductivity, pavement specific heat, and the concrete-heat pipe interface resistance. The use of this model, with the previous assumptions, in the analysis of the earth heat pipe slabs allows the determination of the ground to heat pipe resistance. However, application of the model to an earth heat pipe slab is made more difficult because of condenser blockage. The extent of condenser blockage showed a marked increase over the time period between the first winter's and the second winter's testing, indicating the condenser blockage is largely due to generation of noncondensible gas. This does not mean, however, that some of the blockage is not due to liquid traps created during the installation of the system.

To evaluate this system under actual field conditions, the West Virginia Department of Highways installed an experimental earth heat pipe demonstration project. The installation was on an off ramp at the Oyler Avenue Interchange with an ADT of 483 in Oak Hill, WV. The ramp is approximately 1,200 feet long and sixteen feet wide. Pipes were installed parallel to the longitudinal direction of the ramp with row spacing approximately eight inches apart. To obtain the calculated energy requirement of 10 kilowatt hours (34,130 BTU), 122 cubic feet of earth are required to provide heat for each square foot of pavement.

Construction was accomplished without significant difficulty using normal construction equipment and practices. Holes were drilled with an air track drill, pipes were bent with a small hydraulic bending tool. All problems reported during construction were overcome.

The observed performance of the system was very good when subjected to perhaps the most severe winter this area has ever experienced. The total bid price for the heating system was $415,000 or $195 per square yard.

Snow removal by the embedded pipe method was first considered when it was noticed that snow failed to accumulate or was readily melted at locations where heating pipes were buried close to the surface of a sidewalk or paved area, or where the heating pipes of a central heating plant were placed below the ground surface along the basement walls. In some instances where the heating pipes were closely spaced beneath a sidewalk leading from a building to another area, the result was a very effective snow-removal system.

These accidental snow-removal systems naturally led the maintenance engineer, and other personnel concerned with the problem of snow removal, to see the great potential offered by this method.

One of the oldest known designed snow-melting systems was developed in 1925 [110] when a public utility company installed steam pipes under sidewalks on two sides of its building and manually admitted steam under low pressure into the network of pipes where snow or ice removal was desired. Other private companies with a central steam-heating system also experimented with snow removal from sidewalks, driveways, and other small areas. All of these early installations were satisfactory to a degree, but it soon became apparent that many problems of design and operation had to be solved before this method of snow removal would be completely adequate.

The major problem in the adaptation of embedded pipes as an effective means of snow removal is the availability of an adequate amount of economical power. Initial installations utilized steam or heat sources that were already available for heating or other purposes. However,

TABLE 20: INSTALLATION AND OPERATING COSTS FOR EMBEDDED PIPES [108]

LOCATION	TYPE OF INSTALLATION	INSTALLATION COST		OPERATING COST	
		per Square Meter	per Square Foot	per Square Meter	per Square Foot
Klamath Falls, Oregon	Natural Hot Springs	9.36	0.87	0.301	0.028
John F. Fitzgerald Expressway	Purchased Steam Power	38.43	3.57	1.432	0.133
Chicago Calumet Skyway Bridge	Complete Heating Plant	40.36	3.75	*	*
Indiana Toll Road	Complete Heating Plant	45.53	4.23	0.237**	0.022**

* information not available
**estimated during design

embedded-pipe systems for highways usually require special installations to provide an adequate heat source to heat the circulating heat-transfer fluid and the economy of these installations must be justified exclusively on the basis of snow-melting efficiency, benefits and costs [108]. In general, the operating costs of an embedded-pipe system will be found less than those of an equivalent system of embedded electrical elements, while the installation costs are generally comparable [108]. Installation and operating costs for various embedded pipe systems were determined by and summarized as shown in Table 20. Various fluids may be used when adapting stored earth energy for pavement heating.

The most widely recongized fluids for use in snow-melting systems are steam, water with anti-freeze, and organic heat transfer fluids. The use of steam directly fed to the pipes is considered due to its availability at low cost. Steam, however, has considerable corrosion potential. Further, if the system is shut down for any length of time, any condensate in the pipes may freeze. The combination of water with anti-freeze (usually ethylene glycol) relieves the user of trouble from frozen pipes. This accounts for the wide usage of water-ethylene glycol mixtures for snow melting systems. In many applications, a fluid with superior heat transfer properties is required. The organic heat transfer fluids have been designed to fill this need. The selection of a fluid for any particular application is dependent upon the demands of the design. Each fluid should be compared on the basis of heat transfer characteristics, corrosive properties, replenishment, friction through pipes, effect on system life, operation, and cost [111].

Problems have arisen as a result of reviewing existing installation of embedded-pipe snow melting systems.

Embedded-pipe systems are not generally adaptable to existing highway structures. An overlay of material on an existing structure to provide sufficient depth of bury for pipes poses structural problems. Usually, it is necessary to restrict the use of this type of system to new structures, which should be specifically designed for the additional deadload [108].

The process of embedding heating pipes into an existing facility involves complete bridge-deck replacement and other structural modifications, due to the extra weight of the pipes. The pipe diameters normally used for embedded systems are too large for an adequate cover to be provided by a bituminous overlay.

The problem of pipe placement is especially critical since any mistakes or errors are encased in concrete and not easily corrected.

If the system is not operated continuously, sufficient time must be allowed for slab warm-up before any snow removal can be accomplished. One method of eliminating this delay in snow removal, which is often practiced, is the immediate operation of the system at low or "idle" heat whenever the climatic conditions are favorable for snowfall or icing conditions.

Even though an embedded pipe system may be under-designed for a severe snowfall, or if operation prior to the snowfall is delayed, prompt operation when the snow starts to fall will usually provide a sufficient amount of heat at the surface to prevent the adhesion of snow or ice. Even with some snow on the surface, traction is maintained until the system attains operating temperature.

The heated pavement in Klamath Falls has remained completely free of any accumulation of snow or ice during its operation, and within a short time after the precipitation stops the pavement is completely dry. The ramps leading to the John F. Fitzgerald Expressway have also remained accessible during periods of heavy snowfall and icing conditions. In contrast, similar facilities in these areas without snow-melting systems have proven hazardous and often impassable.

Another alternate form of pavement deicing systems is the use of infrared heaters. Infrared generators have been used successfully for warming outdoor areas and, in limited applications, for melting snow. However, they are not considered feasible for major highway installations at their present stage of development. Maximum efficiency of the units cannot be realized under the conditions of highway service. There are also installation and operating problems. For these reasons, costs for the usual type of application would be inordinately high for an adequate installation [108].

NCHRP Report #4 [108] and APWA Special Report #30 [112] contain a more complete discussion of infrared systems, design criteria, installation costs and potential problems with installations of this type.

Electrically conductive asphalt for control of snow and ice accumulation experimented by L. D. Minsk at the U. S. Army Cold Regions Research and Engineering Laboratory [113] found them a potential safety hazard. Accidents are likely to occur in which metal conductors fall across the conductive asphalt, or perhaps penetrate the surface. This aspect of safety was the basis for the design criterion of a six volt per foot potential gradient. Rudimentary tests to investigate the potential hazard where made on the 1 1/2 #2 panel on a dry, warm day. A steel channel across the panel (energized at 80 volts across the outer conductors) caused little change in the current flow. However, loading the panel with about 150 kilograms (325 lbs) caused a significant jump in current of 30 percent. Water alone across the panel resulted in an imperceptible change in current.

The current increased less than ten percent when the unloaded steel channel was placed on the wet panel. A final test was performed by grooving the asphalt about 1/2 inch deep for a length of three inches and placing the steel channel across the dry panel and in the groove. When the channel was loaded by two people stepping on the ends, the current increase was greater than 40 percent. The safety hazard is thus great enough to require a protective surface coating; no studies of such a coating have been undertaken.

NCHRP Report #4 [108] summarizes the results of installations of embedded electric cables of various types in Michigan, Oregon, and Great Britain. Also, insulated heating cable sites are examined for Salem, Oregon; Aberdeen, South Dakota; Witchita Falls, Texas; Amarillo, Texas; Newark, New Jersey; Peterboro, New Jersey; Lubbock, Texas; Toll Facilities; Great Britain and Switzerland. A detailed study looking at closts and characteristics of an electric heating system are reported in [96].

Economics, or costs, are a major factor in the selection and operation of a successful electrical snow-melting system. Although Great Britain is not subject to extreme winter conditions, over the past few years several miles of heated roadways and bridge decks have been constructed and operated with satisfactory results. This can be done only if costs of installation and operation are reasonable.

The costs of installation and operation depend on many variables which complicate the problem of estimating average costs without knowledge of the specifics for each location. The major controlling factors are (1) design criteria-removal rate and type of electrical elements; (2) power location - additional power supply required at site; (3) method of operation - continuous, manual, and automatic; (4) power rates - demand charge and consumption charge. Only through a favorable combination of these factors can an economical snow-melting system be constructed and operated.

If it is desired to maintain the surface dry and free from snow and ice under all conditions, weather data for the specific location must be investigated, with the extreme conditions controlling the design heat-output per square metre (foot). However, if some accumulation of snow and slush can be tolerated, as long as the surface bond is broken, a smaller heat output can be specified.

Many installations have been designed to melt all the snow as it falls; therefore, the cost of installation and operation have been extremely high. In some instances, costs have been reduced by heating only the wheel tracks, but this results in possible hazardous conditions when icy edges form along the clear wheel tracks.

The one factor which accounts for a large part of the installation cost is the provision of electrical power at the site, if it is not already available. Unless excess or unused seasonable power is present at the location for the snow-melting system, installation costs usually are doubled over the normal cost for electrical cable, control equipment, and labor.

In addition to the costs of making the power available, high operating costs are another drawback to the widespread use of electrical power for snow-melting purposes. Operating costs vary with the individual utility companies, but usually include a demand charge plus an energy charge.

Table 21 gives the wide range of installation and operating costs for highway installations involving electrical deicing or snow-melting systems. These costs are taken from ordinary records, and may not represent the same items of expenditure in every case. Many agencies have not kept complete data on the cost of electrical equipment and supplying power where the heated area was small or the test was considered experimental.

The use of reinforcement mesh apparently results in lower initial installation costs than the use of resistance cable (Table 21). This is to be expected. On the other hand, operating costs for the mesh may be expected to be higher because of the special transformer equipment needed and higher resulting demand charges.

In Salem, Oregon, the opposite was true; all of the transformers were owned by the operating agency. In this case, the operating costs should probably be comparable for equivalent power outputs. The higher operating cost of the wire mesh in Salem may be the result of using more power to compensate for broken grids, or possibly the inclusion of annual maintenance and repair costs.

The high installation costs experienced by the Illinois State Toll Highway Commission and the South Dakota Department of Highways apparently include all associated costs for complete installation. Again, these costs are heavily dependent on the availability of power and the cost of supplying it at the site.

The Wichita Falls installation, which was designed to maintain the bridge roadway clear of ice as long as the approach roadway does not freeze over, was constructed with heat outputs of 11, 22, 43 watts per square meter (5, 10 and 20 watts/sq.ft) at an average installation cost of $15.97 per square meter ($1.48/sq.ft.). A transformer station for supplying the necessary power was not included in this unit cost.

TABLE 21: INSTALLATION AND OPERATING COSTS FOR EMBEDDED ELECTRICAL ELEMENTS [108]

LOCATION	INSTALLATION COST						OPERATING COST			
	WIRE MESH REINFORCEMENT LESS COST OF TRANSFORMERS		RESISTANCE CABLE				WIRE MESH		RESISTANCE CABLE	
			LESS COST OF TRANSFORMERS		WITH COST OF TRANSFORMERS					
	per Square Meter	per Square Foot	per Square Meter	per Square Foot	per Square Meter	per Square Foot	per 100 Square Meters	per 1,000 Square Feet	per 100 Square Meters	per 1,000 Square Feet
Michigan Test Section	$ 8.93	$0.83					$0.76[a]	$0.71[a]		
Salem, Oregon	10.76	1.00	$25.08	$2.33			0.23[b]	0.21[b]	$0.18[b]	$0.17[b]
Wichita Falls, Texas			15.93	1.48					0.54 to 1.08[c]	0.50 to 1.00[c]
Amarillo, Texas					$25.73[d]	$2.39[d]			0.15	0.14
Passaic River Bridge, N.J.			16.79	1.56					2.80	2.60
Proposed Installation, N.J.			31.97[d]	2.97[d]					3.93[e]	3.65[e]
Chicago Tollway					65.23	6.06			f	f
Aberdeen, South Dakota					52.74	4.90			f	f

a Average asphalt and concrete section.
b Based on 110 operating hours.
c Includes demand charges for utility-owned transformers.
d Low bid price, average cost for roadway and structure.
e Estimated, winter months; Includes demand charges for utility-owned transformers.
f Not available.

As a comparison, installation costs including the cost of three, 333 KVA transformers for the Amarillo snow-melting project was as follows:

TABLE 22: INSTALLATION COST FOR THE AMARILLO SNOW-MELTING PROJECT [108]

HEAT OUTPUT (watts)		COST	
PER SQUARE METER	PER SQUARE FOOT	PER SQUARE METER	PER SQUARE FOOT
376.7	35.0	$42.63	$3.96
269.1	25.0	30.46	2.83
188.4	17.5	21.31	1.98
134.5	12.5	15.18	1.41

The cost per square meter (foot) increases for higher wattage requirements; therefore, it is particularly important that the correct design wattage be chosen for electrical snow-melting systems.

The problems and difficulties associated with the installation of electrical elements are similar to those for embedded pipes, and, in some instances are even greater in number [108]. Although the electrical elements can be incorporated with a resurfacing project making their use more attractive, it also creates more difficulty in placement.

All of the problems of embedding pipe in the slab apply when conduit is used as an avenue for the electrical heating elements. A damaged or corroded conduit offers no protection and may hasten deterioration or cause an electrical failure. Because of the increased diameter, conduit normally may be employed only with new construction, not resurfacing.

In new construction the heating elements or cables are either attached to the reinforcing network in grids of predetermined lengths, widths and spacings prior to concrete placement; or mats of the correct lengths, width and cable spacing are formed from the heating elements and then placed prior to the final 4 or 5 centimeters (1-1/2 or 2 in.) of concrete.

With good construction practices, an electrical system will apparently give many years of satisfactory service with minimum maintenance costs.

Snow melters and central melting sites have been employed for the purpose of snow and ice control on some city streets, but have not made an entry to highway segments or networks as an economically feasible alternative to present practices. The American Public Works Association [114] has identified systems that are in use, and details some of their characteristics.

As a general use the various type of pavement heating systems are not economically feasible as an alternate to methods presently being used, however in specialized areas such as high accident ramps, intersections, etc., one of these systems may be justifiable economically on a basis if analyzed separately for each location under consideration for use.

Storage and Stockpiling

Storage of deicing materials may be in open stockpiles, under cover, or packaged separately in bags [115].

The Environmental Protection Agency has detailed specific measurements and design criteria for a number of storage or cover facilities, including; wooden rigid frame storage building, wooden rigid frame storage building with loading ramp, dual storage building for materials and equipment, concrete and wood storage building, storage crib with sliding roof, open-face concrete block and timber shed, braced timber storage shed, dome storage shelter, creosoted timber storage shed, storage under a viaduct, covered outdoor storage piles and overhead hoppers. Any one of these methods of storage may be the most economical

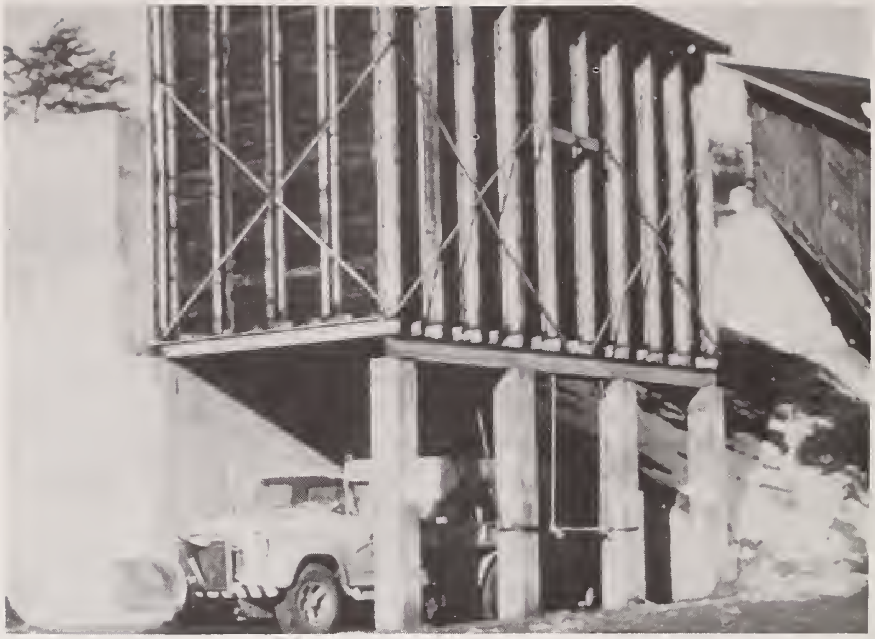


FIGURE 66 BIN SALT STORAGE SITE (Courtesy Virginia Department Of Transportation)

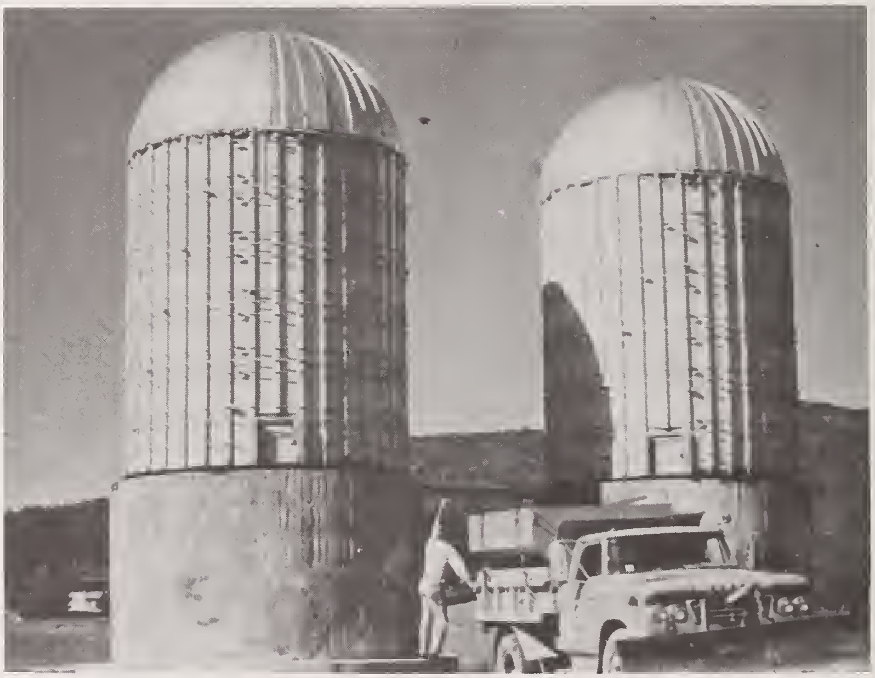


FIGURE 67 SILO SALT STORAGE SITE (Courtey Virginia Department Of Transportation)

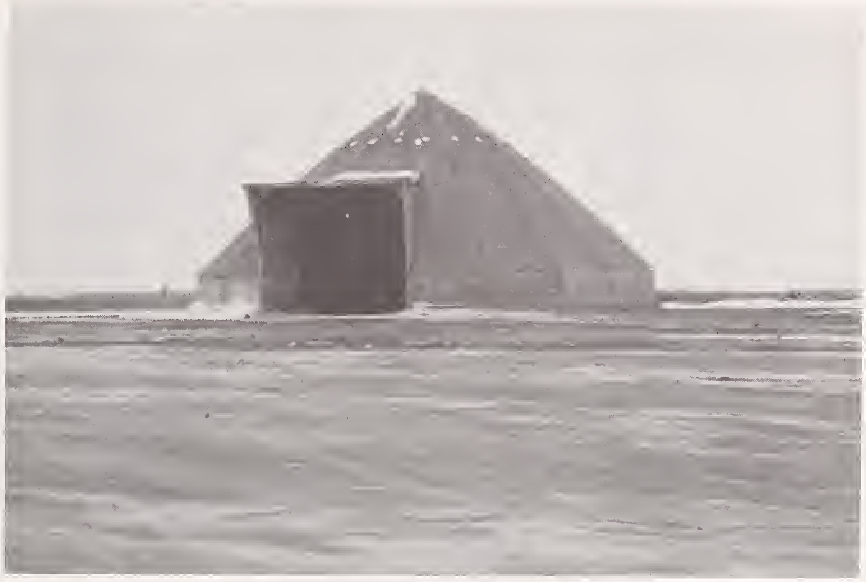


FIGURE 68: DOLMAR DOME STORAGE SITE (Courtesy Minnesata Department Of Transpartation)

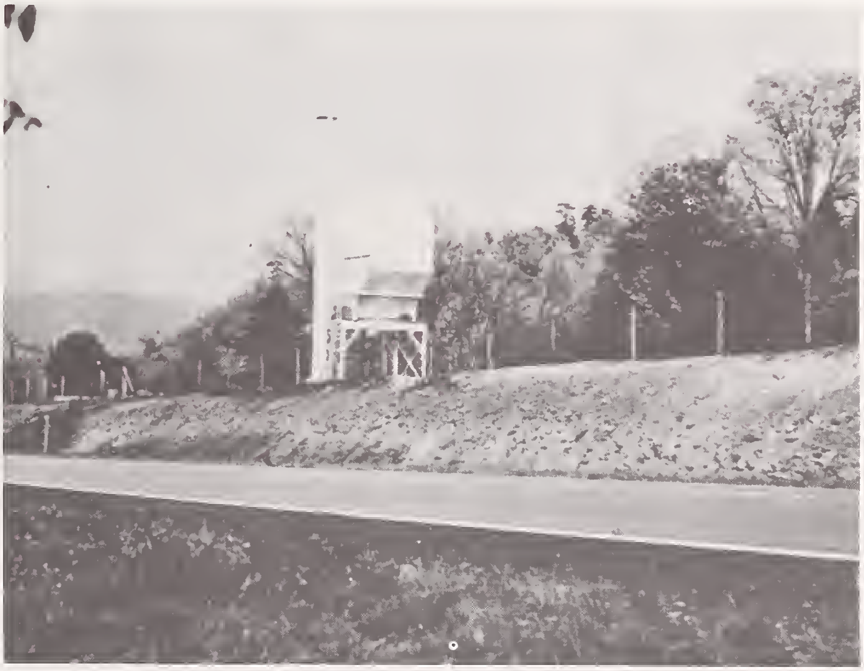


FIGURE 69 ROADSIDE BIN SALT STORAGE SITE (Courtesy Virginia Department Of Transpartation)

depending on material to be stored and what it is to be protected against. Also, included in a capacity and cost summary for salt storage, site selection and design information.

In addition to covered storage of deicing materials, several states store abrasive, salt and/or premix combinations in unprotected stockpiles. This poses a problem for the salt in that caking may become a functional and expensive problem. To combat this, the use of anti-caking agents such as YPS (see Environmental Chapter) may be added. Utah's specification on salt is included in the appendix. Here the YPS has been reported as retarding the caking characteristics of the salt stockpile except for the outer 2 to 6 centimeters (1 to 3 in.) which is easily broken by hand.

Experiences with storage of various types of deicing material have been reported [116] and it appears that the type of storage facility used should be based upon an individually engineered solution for each location to be applied or an acceptable policy that may be easier implemented on a statewide basis. Whatever approach and solution is found, it should be in harmony with potential environmental impacts for the policy, local political influences and reflect the public opinion or desires for that location.

Premixing of materials for snow and ice control is accomplished almost entirely by unloading specified amounts of the premix constituents available at a given maintenance stockpile. A few states use bag chemicals mixing them by hand with other materials. Conveyor and hopper systems are used to a very limited extent to premix deicing materials. As compared with other maintenance activities in snow and ice control, the activity of premixing deicing materials appears to be the most inefficient in the snow and ice maintenance procedures. Of total material costs, the premixing cost can be as high as one-third of the total cost.

Rate of Application

The optimum application rate is a function of: level of service desired, weather conditions and their change with time, state and characteristics of the chemicals used, time of application, traffic density at the time of subsequent to chemical application, topography and the type of road surface.

However, determination of the proper application rate is a matter of judgement and a guess as to weather conditions immediately following the application. If a treatment is made based on the expectations that a storm will continue for several hours but it doesn't, the amount applied will have been excessive. Few maintenance organizations are equipped or staffed to apply a minimum treatment followed by a second treatment should observations indicate the necessity. In some cases, policies call for the threatment of lower-priority roads after the most critical highways are treated; if a second treatment of critical highways is necessary, the lower-priority roads must be left untreated for a longer time. This leads to the practice of operators choosing an arbitrary application rate that will reasonably cover as many of the unknown future contingencies as possible, even though this results in excessive application when a storm condition unexpectedly moderates. Traffic may soon whip off loose dry chemicals or splash off a high-brine-content slush when heavy initial chemical treatments are applied.

The practice of applying chemicals in increments, as needed, represents one of the most useful methods of reducing the quantity of chemicals applied and increasing the amount of effectively utilized for deicing or anti-icing [4].

Observations of the behavior of wet snow under actual traffic conditions by Schaerer [117] led him to conclude that snow with a free-water content less than fifteen percent was compacted and formed a hard slippery surface. Snow with a free-water content of 15 to 30 percent was usually not compacted but remained on the road in a soft, loose state. Snow with greater than 30 percent free water was removed by traffic. The British Transport and Road Research Laboratory recommends the application of sodium chloride at a rate of 48 grams per millimeter of snow per square meter per degree C (1/8 lb./in. of new snow/sq. yd/°F) below freezing on roads with a traffic density more than 50 vehicles per hour for removal of the snow by traffic action [118]. This is equivalent to 564 kilograms per two-lane kilometer per 2.5 centimeters of snow per degree centigrade (1,760 lbs./two-lane mi./in. of snow/°F) below freezing. This quantity of chemical is sufficient to produce between 30 and 40 percent melting. Such high application rates are not common in the United States.

Vermont applies 136.07 to 362.87 Kilogram per two-lane kilometer (300 to 800 lbs./two-lane mi.) depending on the situation. The state maintenance engineer must report any application exceeding 225.0 kilogram per kilometer (800 lbs./mile) to the State Department of Water Resources within fourteen days.

Standard application rates in Maine are 113.0 kilogram per two-lane kilometer (400 lbs./2-lane mile), but it can be raised to 169.0 kilogram per kilometer (600 lbs./mi.) under heavy icing conditions.

Massachusetts has standardized an application rate of 98.6 kilograms per lane-kilometer (350 lbs./lane-mile) of straight salt for temperatures -4°C (25°F) and rising, and a 1:1 premix (sodium chloride: calcium chloride) for -4°C (25°F) and dropping. This rate is not varied; instead, field personnel must justify the number of applications made. The 98.6 Kilogram (350 pound) rate has been arrived at by experience in achieving a desired margin of safety. Experiments have shown that 56.4 to 70.5 kilogram per lane kilometer (200 to 250 lbs./lane-mile) frequently Allowed compacted snow to develop. However, experimental applications at the rate of 56.4 to 70.5 kilogram per lane kilometer (200 to 250 lbs./lane mile) of the 5:1 sodium chloride-calcium chloride premix will be made at the warmer temperatures of -4°C (25°F) and rising, in order to reduce chemical quantity. This will consequently increase costs (1972 prices: salt $13.15 per metric ton, premix $19.80 per metric ton ($14.50 per ton, premix $21.80 per ton)).

Salt application rates for municipalities run as high as 282.0 to 563.7 kilogram per two-lane kilometer (1,000 to 2,000 lbs./two-lane mile). New York City used .095 kilograms per square meter (1/4 lbs./sq. yd.) or approximately 845.5 kilograms per kilometer (3,000 lbs./mile) during the early use of salt in the late 1940's, but now applies salt at the rate of .035 kilograms per square meter (1/8 lbs./sq.yd.). This is the quantity yielded by the minimum opening of the rear gate on spreaders, and local field tests have shown this is adequate for freezing rain and light snow. Bus routes and federal and state numbered routes always receive treatment; other roads are treated on the basis of ADT (average daily traffic), sharp curves, and steep grades. Hazardous intersections are also treated.

During the winter of 1971-72, cities receiving 127 centimeters (50 in.) of snow or more applied salt at an average of 11.6 metric tons/lane-kilometer (20.6 tons per lane-mile), those receiving 76 to 125 centimeters (30 to 49 in.) snow applied 5.3 metric tons/lane kilometer (9.4 tons per lane-mile), and light snowfall regions of less than 76 centimeters (30 in.) snow, applied 4.8 metric tons/lane kilometer (8.5 tons per lane mile).

Toll road organizations tend to be more generous in their application of deicing chemicals as compared to states because they, in effect, are selling a service and don't wish to run the risk of damaging the good will of their customers by permitting road conditions to cause undue hazards or delays [4].

The district materials laboratory in Pueblo, Colorado [191] has been experimenting with materials for estimating the optimum percent salt content in sand mixtures used for the removal of snow and ice on highways.

Experiments have been conducted on the higway itself, to determine what sand-salt mixture would be best for accomplishing ice removal, and at the same time limit the effect on the natural environment.

Samples of sand mixes were made consisting of a range of salt and calcium chloride. These include one through eight percent, and one through eight percent mixes of 1:1 ratios of NaCl and $CaCl_2$. The objective is to find the least amount of salt required to remove the snow and ice, accounting for temperature.

The one and two percent sodium chloride mixes failed to react to any significant degree, dry sand proved to be as effective. Mixes consisting of five-six percent indicated the optimum mixture. The eight percent mix was the most concentrated salt content applied and the reaction did not appear to be significantly better than the five or six percent mixes.

The Environmental Protection Agency [15] suggested guidelines for

TABLE 23: GUIDELINES FOR CHEMICAL APPLICATION RATES [15]

WEATHER CONDITIONS				APPLICATION RATE BASED ON A TWO LANE PAVEMENT									INSTRUCTIONS
TEMPERATURE		PAVEMENT CONDITIONS	PRECIPITATION	LOW-AND HIGH-SPEED MULTILANE DIVIDED			TWO AND THREE-LANE PRIMARY			TWO-LANE SECONDARY			
DEGREES C	DEGREES F			APPLI-CATION	kilograms per kilometer	pounds per mile	APPLI-CATION	kilograms per kilometer	pounds per mile	APPLI-CATION	kilograms per kilometer	pounds per mile	
-1 & up	30 & over	wet	Snow		85*	300*		85*	300*		85*	300*	wait at least 0.5 hour before plowing
			Sleet or Freezing Rain		56*	200*		56*	200*		56*	200*	reapply as necessary
-4 to - 1	25 to 30	wet	Snow or Sleet	initial repeat	110* 56*	400* 200*	initial repeat	110* 56*	400* 200*	initial repeat	110* 56*	400* 200*	wait at least 0.5 hour before plowing; repeat
			Freezing Rain	initial repeat	85* 56*	300* 200*	initial repeat	85* 56*	300* 200*	initial repeat	85* 56*	300* 200*	repeat as necessary
-7 to - 4	20 to 25	wet	Snow or Sleet	initial repeat	140* 70*	500* 250*	initial repeat	140* 70*	500* 250*	initial repeat	340*** 340***	1200*** 1200***	wait about 0.75 hour before plowing; repeat
			Freezing Rain	initial repeat	110* 85*	400* 300*	initial repeat	110* 85*	400* 300*	initial repeat	340*** 340***	1200*** 1200***	repeat as necessary
-9 to - 7	15 to 20	dry	Dry Snow	plow			plow			plow			treat hazardous areas with 340 kg (1200 lbs) of 20:1 Sand/Salt Mixture
		wet	Wet Snow or Sleet		140**	500**		140**	500**		340***	1200***	wait about one hour before plowing; continue plowing until storm ends; then repeat application
below - 9	below 15	dry	Dry Snow	plow			plow			plow			treat hazardous areas with 340 kg (1200 lbs) of 20:1 Sand/Salt Mixture

* = SALT
** = 3:1 SALT/CALCIUM CHLORIDE MIXTURE
*** = 5:1 SAND/SALT MIXTURE

chemical application rates are presented in Table 23.

They further state that these guidelines reflect the lower limits of chemical usage in current practice among a wide range of city, town, county, state, and toll-road authorities. Five classifications of roads comprise the basic categories. The guidelines are presented in terms of the amount of material that is to be spread upon a kilometer (mile) of two-lane road or per kilometer (mile) of two lanes of a divided highway.

The Pennsylvania Department of Transportation has experimented with premix ratios consisting of one part calcium chloride and five parts sodium chloride [43]. Recommendations include spreading salt and deicing chemicals at 225 kilogram per kilometer (800 lbs/mile) on ice and approximately 141 kilograms per kilometer (500 lbs/mile) on packed snow. In practice they have found it necessary to increase application rates up to 423 kilograms per two-lane kilometer (1,500 lbs/two-lane mile). Resulting recommendations are summarized in Table 24.

Many more recommended application rates have been proposed, depending on the situation, traffic, etc. The Salt Institute, trade journals and several county and local agencies have recommended salt and/or chemical application rates [119].

An economic analysis, depending on material availabiltiy, application rates, temperature and type of service that is desired would best describe the cost effectiveness of material to use in a given location.

TABLE 24: CHEMICAL AND ABRASIVE APPLICATION PROCEDURES SUGGESTED BY THE PENNSYLVANIA DEPARTMENT OF TRANSPORTATION [67]

STORM CONDITION	PROCEDURES BASED ON A TWO LANE PAVEMENT
Condition 1 Temperature - Near -1°C (30°F) Precipitation - Snow, sleet or freezing rain Pavement condition - Wet	If freezing rain, apply salt at 56 Kilograms per Kilometer (200 pounds per mile). If sleet, apply salt at 140 Kilograms per Kilometer (500 pounds per mile.) If snow continues and accumulates, plow and salt simultaneously. If rain continues to freeze, reapply salt at 56 Kilograms per Kilometer (200 pounds per mile).
Condition 2 Temperature - Below -1°C (30°F) and Falling Precipitation - Snow, sleet or freezing rain Pavement condition - Wet or sticky	Immediately apply chemical at 140-170 Kilograms per Kilometer (500-600 pounds per mile). If freezing rain, at 56-110 Kilograms per Kilometer (200-400 pounds per mile). If snowfall continues and accumulates, plow and repeat chemical application simultaneously.
Condition 3 Temperature - Below -7°C (20°F) and falling Precipitation - Dry snow Pavement condition - Dry	Plow as soon as necessary. Do not apply chemicals. Continue to plow and patrol to check for wet, packed or icy spots; treat them with heavy chemically treated antiskid material.
Condition 4 Temperature - Below -7°C (20°F) and at Night Precipitation - Snow, sleet or freezing rain Pavement condition - Wet	Apply chemicals or antiskid material as often as required by traffic conditions. If temperature starts to rise apply chemicals at 170-230 Kilograms per Kilometer (600-800 pounds per mile), then start plowing as soon as feasible. Continue until bare pavement is obtained.
Condition 5 Temperature - Below -12°C(10°F) Precipitation - Snow and freezing rain Pavement condition - Accumulation of packed snow or thick ice	Apply antiskid. Apply chemicals at the rate of 140 Kilograms per Kilometer (500 pounds per mile). When snow or ice becomes slushy, remove by plowing. Repeat application and continue blading until pavement is clear.

Safety Methods For Equipment in Snow and Ice Control

A review of trade magazines generated procedures used by various agencies involved with snow and ice control on increasing their safety, safety to men and the roadway user while performing the snow removal activities.

Better Roads [77] asked the three questions:

1. Are your snowplow units equipped with any extra or unusual warning devices to attract the attention of motorists in order to avoid collisions with the snowplows?

2. What special instructions do you give your operators to help them avoid this kind of incident?

3. Have you found any ways to inform the public of this dangerous situation? Have any of your information programs proved effective?

Some of the replies were:

In Cass County, North Dakota snowplow units are equipped with the usual headlights, clearance lights and a large amber flashing light on top of the cab, as required by law. Operators are instructed to keep the flashing light operating at all times while snowplowing on a public road.

In Michigan trucks are equipped with the usual set of lights, although tail lights have what is called a "hot bulb". This bulb produces enough heat to keep the snow melted off the tail light. Also, they have a light directed at the underbody scrapers.

Each fall, operators are given a refresher course in the operation of snow-removal equipment.

In Montgomery County, Ohio, notification is forwarded to "Air Scout" when a storm arrives to warn the traveling public of the icy roads and to tell them to be on the look-out for salt trucks.

In Indiana, all State Highway trucks that carry underbody scrapers and front-end snowplows are equipped with rotating beacon lights as well as other clearance lights fore and aft. In addition to these, the underbody-scraper units have red flags mounted on flexible shafts attached to each end of the scraper. Some have a reflector disc mounted on each end in addition to the flags.

In general, drivers do not receive any special instructions, other than the constant reiteration of the usual instructions for safe driving under adverse driving conditions.

Illinois has experienced a rather alarming number of accidents involving snow and ice-control trucks. The causes of these accidents are numerous. A large number of them, however, result from the following situations:

- Motorists are following trucks too closely and, when trucks make an abrupt stop, the following motorists are unable to stop in time to avoid rear end collisions.

- A number of accidents occur when truck units are plowing and hit either packed snow or an obstruction in the pavement. This causes the plow to trip and consequently throws the truck across the centerline. Usually this situation results from truck operators attempting to plow at too-high speeds.

Safety oriented programs to combat the problem include equipping snow and ice-control trucks with additional lights. An amber revolving type of light is mounted on a self-leveling bracket, which is mounted in the center of the dump-body cab shield. An additional seven inch diameter tail light is mounted on the upper left corner of the cab shield. Another 18 centimeter (7 in.) red light is mounted on the upper right corner of the cab shield. In addition to the two conventional combination tail light, stop light and turn-signal lights mounted on the rear of the truck frame, an additional combination tail light, stop light and turn-signal light is mounted on the upper left and right rear corners of the dump body. Also, 43 by 51 centimeter (17 x 20 in.) red warning flags are mounted on the left rear corner of the dump body and on the left front corner of the front bumper. Attempts are made to maintain this same size red flag on each end of the snowplow moldboards. Various attempts have been made over the years to mark the ends of the snowplows with lights, reflectors and various types of reflective paint. None of these ideas, however, has proved satisfactory.

Operators are warned that plowing operations should not be attempted at speeds in excess of 40 kilometers (25 miles) per hour.

E. B. Hodgins, Maintenance Engineer for New Hampshire Department of Public Works and Highways, wrote in Public Works in August 1971 [128] that

> *...for several years we have been alarmed by the increasing number of accidents resulting from vehicles overtaking our plow units. We improved our warning light systems, thinking that any prudent driver of an overtaking vehicle would recognize a slow moving vehicle ahead. Involvements continued, however, sometimes with the plow truck itself and sometimes with the wing plow, which may project four feet to the right or left of the normal clearance line of the truck.*
>
> *An overtaking operator finds a constantly decreasing snow accumulation as he closes the distance to a plow ahead, and generally increases his speed accordingly.*

The operator of the plow truck, on the other hand, finds an increasing accumulation of snow or, at least, all that has fallen on the roadway since his last pass. The truck operator has poorer visibility than does the driver coming up behind him. Snow escaping from the moldboard of the front-mounted plow, plasters the windshield. The standard truck headlights are blocked by the plow, so auxiliary lights are mounted at about the height of the operator's eye. In night operation, the glare from these lights on the falling snow is a constant problem for the driver of the truck. The overtaking driver, with his lights at low beam, has fewer problems with visibility.

It seems that any hope of reducing the accident rate must come from reducing the speed of the overtaking vehicle, or increasing the speed of the plow truck.

States responsible for maintaining snow and ice on highways that have numerous curves and/or are subjected to severe winter storms and blizzards have found that snow poles aid considerably in delineating a path for plow operators and the driving public. These vary in color and height. Snow poles are placed at selected spots or can be attached to existing highway appurtenances (delineators, guardrail, etc.) for economy. Flags attached to the top of snow poles have been reported as helpful driving aids during poor visibility conditions. For economic reasons, snow poles can be left in place year round but are usually removed every spring and replaced in the fall.

Consideration should be given to standardize many of the operating procedures and safety equipment on maintenance vehicles between states. Presently, amber lights will be found on snow plows and other maintenance equipment in one state and blue lights on the same type of equipment across the state border. Yellow vehicles on a particular stretch of highway are used and beyond the state line another color is found. Standardization of basic color warning systems, to promote less confusion to the road user during poor visibility or bad weather, would be helpful.

Routing

For a typical maintenance responsibility area, there are numerous alternatives for locating stockpiles of salt and abrasives as well as the storage of winter maintenance equipment. At the onset of a storm, these are the locations from which snow removal equipment begins its tasks of removing snow and/or spreading deicing or anti-skid materials. The question arises, what sequence of routes should be assigned to a particular truck to optimize time in use, and minimize fuel consumption, and number of trucks and manpower required? There are many factors to be considered in equipment routing: the characteristics of the particular storm, the time of day, the day of week, the immediate availability of manpower, the layout of the local road system, and others. Even though specific routes are preassigned to particular trucks, it is not uncommon that on-the-spot changes must be made because of drifting, icing or accidents.

Freedom at the foreman's level to make changes in response to momentary conditions is a desirable managerial policy, but it is still necessary to have a standard operational plan. In the past such plans were formulated on the basis of the experience of the foremen and other managerial maintenance personnel. This method has the advantage that intrinsic features of the road system, traffic demand and trouble spots are well-known by those who service the roads. Yet the question remains whether from the large number of possible routings for each truck of a fleet the best possible ones have been chosen or if it makes much difference what the nominal plans are [129].

A linear programming model can only consider one particular objective, while it is obvious that there are many criteria involved in determining an acceptable routing strategy.

One important criterion for a routing strategy is the minimization of the total time for servicing all roads of a system, or of the total number of truck miles necessary for completion of the standard plan. Another criterion could be the minimization of deadheading or of setup time (the time required by a truck to travel from the stockpile to the beginning of the route to be serviced by it).

The Pennsylvania State University, in conducting a study for the Pennsylvania Department of Transportation, chose as their objective of a linear programming model to minimize the total number of truck miles required to service a given road system. A second model attempted to incorporate notions of priority and the dynamic needs of the public. The timing of service in relation to the storm and the relative effectiveness of the service is formulated via a structured random sampling technique.

The criterion for the model is the minimization of truck miles incurred subject to the constraint that all roadways in the system are serviced. It will be assumed for the sake of simplicity that all roadways in the system, which will be called links, are of the same length. This assumption is not necessary but makes the development less cumbersome.

This model has some interesting theoretical aspects, but the research group came to the conclusion that other routing strategies, for instance graph theory and simulation, should be significantly superior. The major difficulty with the linear programming method is that for even a medium sized system, the number of constraints and variables becomes too large to handle easily. Furthermore, the process of converting the noninteger solution into an integer solution is quite subjective and is difficult to apply even for an expert in mathematical programming. In short, a great deal more work would have to be done on this method to make it of practical value to the truck routing problem.

Random routing is done many times over, and the routing strategies that service the higher priority roads earliest are, of course, going to receive the highest total scores. If a truck must travel a road that has already been serviced, it receives a score of zero for the corresponding units of time. In this manner, routings with a large amount of duplication will score low and hence will not be viable contenders for the set of best routings generated by the program.

Once the benefit-time curve has been constructed and the other necessary data is included in the computer program, one can generate any number of possible routing strategies. From a small subset with the highest scores, the strategy that best satisfies other criteria can then be chosen. Of course, the more routing strategies are generated the better is the chance that optimum results are obtained.

Routing is usually determined via snow plans for a particular highway network. To lower costs of maintaining a particular level of service, it may be desirable to alter traditional section or district boundaries for the purposes of snow and ice control. Alterations of these boundaries should be compatible with accessible turn around locations. Overlapping intersections are desirable to avoid missing certain highway segments at the interchanges. Normal maintenance or district boundaries do not always fall at such convenient locations.

Stockpile locations should be determined based on equipment capacity such that "dead heading" for deicing materials or abrasives is not required or held to a minimum. Routes chosen to begin and end near stockpile locations is helpful or establishment of stockpile locations at either end of routes and near highway junctions so the end point of more than one highway segment may be serviced from the same stockpile is an aid in cutting costs.

Bridge Decks

The safety of highway transportation is largely dependent on the highway environment and the driver's awareness of it. A prime example is an icy road condition - especially when it is localized. This often happens with bridges. Not only may the condition by unsuspected by the motorist, but the confines of bridge abutments and railings give him no escape route when trouble occurs [130].

Winter accident reports indicate that a number of highway skidding accidents are caused by the presence of frost or ice on bridges and underpasses caused by a high humidity and a freezing atmospheric temperature. This condition is particularly hazardous when the approaching highway is dry due to higher road surface temperatures that result from the sun's radiation or the heat source provided by the ground.

In 1965, for 2-1/2 years, the Traffic Research Section, Michigan Department of State Highways has been evaluating a detection system that anticipates frost and ice formation during the presence of high humidity

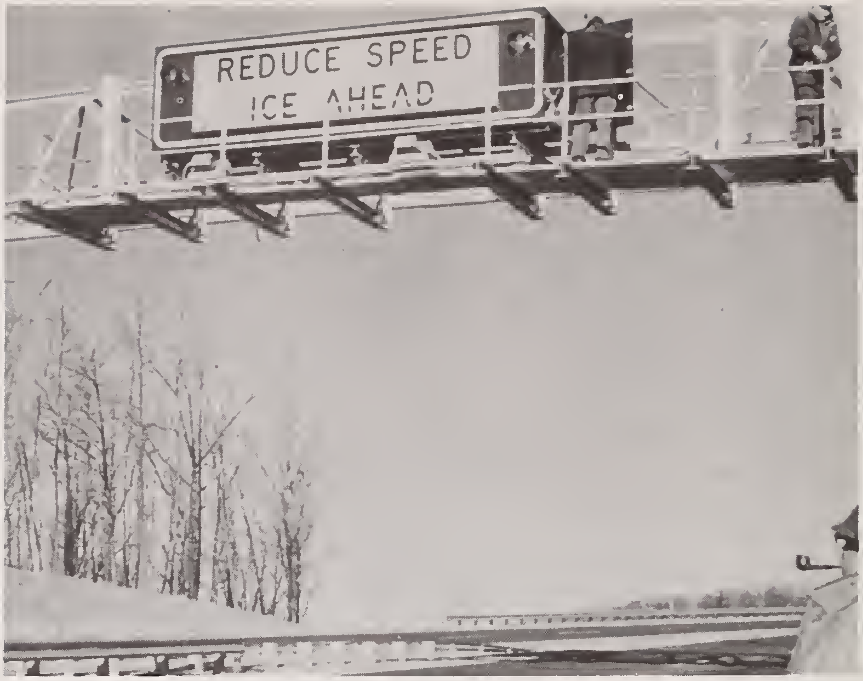


FIGURE 70 OVERHEAD ICE WARNING SIGN (Courtesy Virginia Department Of Transportation)

and low bridge deck temperature conditions and automatically warns approaching drivers of the icy condition by a lighted warning sign. The system also detects the presence of snow or ice due to precipitation when the relative humdity is low and also initiates a warning by a lighted sign.

This system incorporates both humidity monitoring for detecting frost or ice conditions before they form and signal sensors installed in the bridge deck, for monitoring frost or ice formations resulting from precipitation.

The site chosen for the evaluation was the bridge over the Flint River on I-75 west of the city of Flint, Michigan. This location was chosen because the number of accidents caused by slippery bridge decks due to icy or frosty conditions was higher in comparison to other sites which were considered and the site was within a reasonable driving distance for installing, servicing and maintaining the equipment necessary to carry out the evaluation.

Detection of these icing conditions - particularly frost - has been the prime objective of many feasible proposals. A device that properly detects (or predicts) icing could be helpful in many ways. It could send an alert to the maintenance garage; activate salt spreading devices, heating cables or other deicing systems or trigger real-time signing to alert motorists to a condition when it is important. These actions are in contrast to passive "Bridge Freezes Before Pavement" signs that

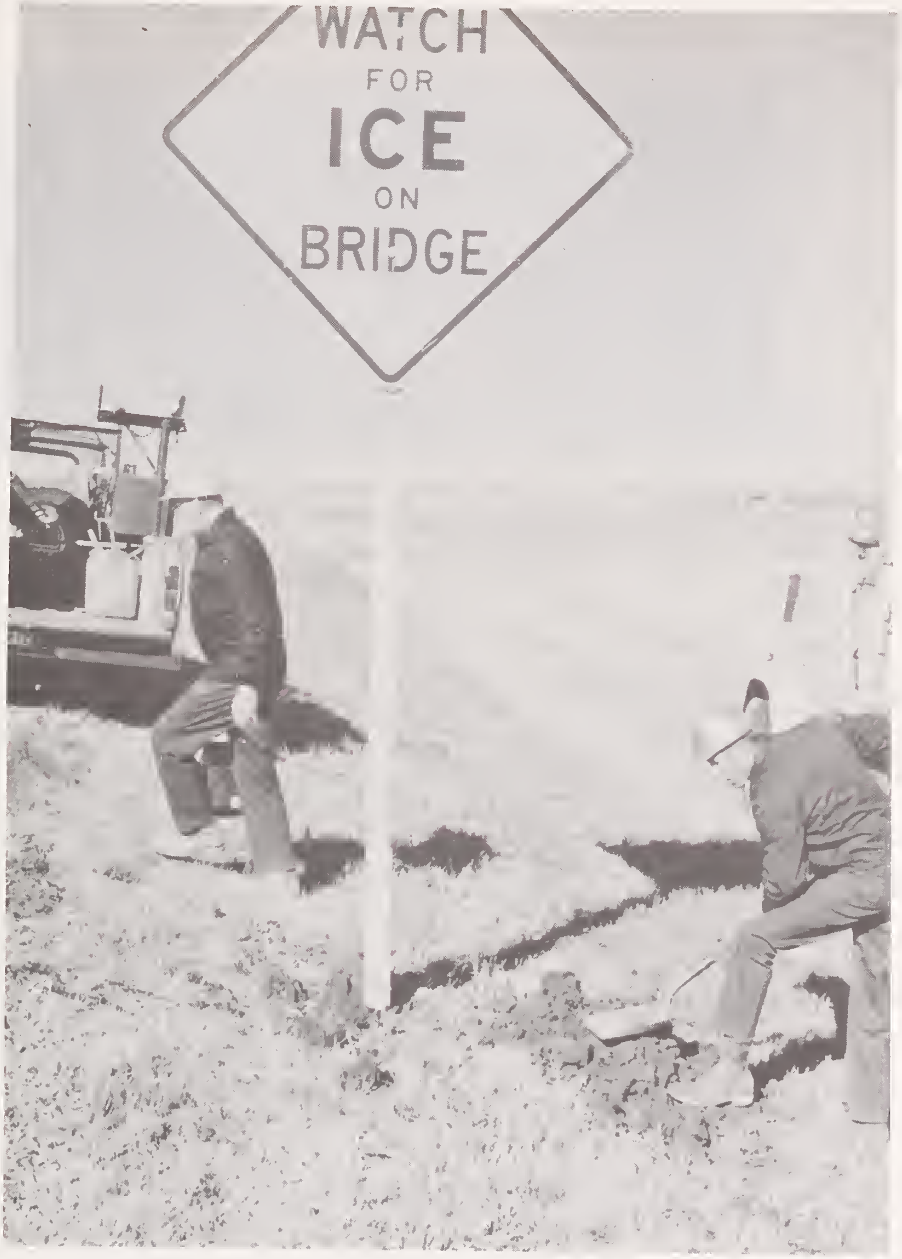


FIGURE 71 INSTALLATION OF SEASONAL SIGNING FOR ICE
(Courtesy South Dakota Department Of Transportation)

are believed to be relatively ineffective.

If the bridge deck temperature equals the saturation temperature of the air, condensation of water vapor on the deck will occur. When the deck temperature falls below the saturation temperature, condensation is accelerated. When the deck temperature is at or below 0° (zero) degrees Celsius (32^0 F), ice will form. Saturation temperature (the equivalent of 85-percent relative humidity) is calculated to be -16.0°C (3.1°F) below the ambient temperature [131].

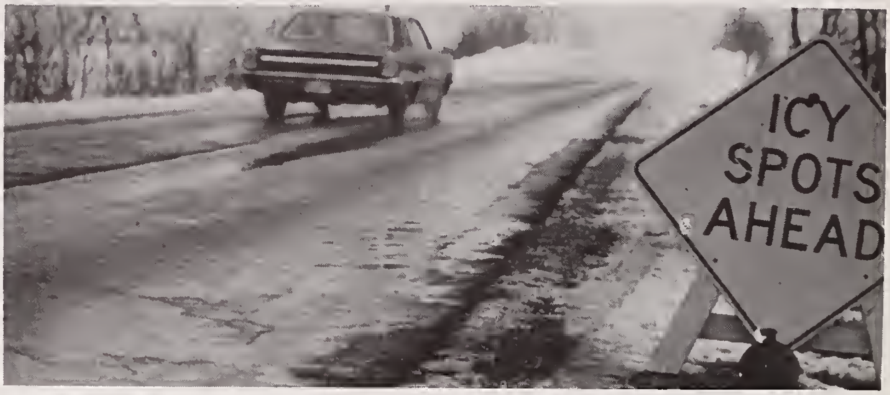


FIGURE 72: TEMPORARY ICE WARNING SIGN (Courtey Virginia Department Of Transportation)

The detection system utilizes a relative humidity transducer and an ambient temperature transducer to continually monitor the relative humidity and temperature of the air. The humidity sensor consists of a humidity sensitive film deposited on a conductive grid. As the humidity rises, the film conductance increases. This phenomena is then translated into voltage analogues in the electronic logic of an amplifier assembly. The humidity sensor housing also incorporates the ambient temperature transducer whose conductance likewise changes with ambient temperature and is also translated into voltage analogues in the electronic logic of the amplifier.

By comparing the differential temperatures, the system predicts when frost will appear on the surface. Setting the electronic logic to take action when the relative humidity to saturation differential is slightly larger than the deck to ambient temperature differential, frost is anticipated before it forms and an ice warning sign is automatically turned on to warn approaching drivers.

To activiate the anticipatory portion of the system (predicting the formation of frost or ice on the bridge deck before it forms) three input signals must be generated before the system provides an output to light up warning signs indicating BRIDGE ICY AHEAD.

1. A bridge deck temperature of 0°C (32°F) or below.

2. A bridge deck temperature of at least -15.8°C (3.5°F) below air temperature.

3. A high relative humidity.

When only one or two of these conditions are present frost will not form on the deck and there will be no output from the system. When all three conditions exist, ice will form, and the system will provide an output to light the warning signs.

In 1966, the State of Iowa Highway Commission decided this was an inefficient method of checking winter road conditions and decided to use radio signals to alert maintenance foremen at their homes when temperature and moisture conditions became right for icing of highways [131].

The system uses two sensors, designed to detect temperature and moisture levels capable of producing ice, imbedded in the bridge floor about midway into one traffic lane.

Caution should be employed when utilizing an alert system to warn of impending ice or frost conditions on bridge decks. Many states, through loss of their sovereign immunity, may be held liable for systems that do not properly activate signs or other warning devices when they should. Experience with some sensors have shown that the alert to a maintenance station, may in fact be false, thus unnecessary costs are generated to control a hazardous condition which does not exist.

Equipment

This section summarizes the basic types and corresponding characteristics of equipment used for snow and ice control on highways. Field experience with the use of various types of equipment where reported is also included. One of the more significant aspects of equipment allocation for any maintenance activity is the corresponding "rental rates" and what criteria is used to establish these. The rental rates typifying states' procedures will be summarized. A general discussion of helpful and money saving ideas that have been tried and proven will be discussed in hopes other highway maintenance operations may find them implementable.

A general summary of equipment deployed [36] for snow and ice control has been presented in NCHRP #42. This report summarized that in the northern part of the United States, the number of equipment units varies with the intensity of snowfall and wind conditions experienced in that area. Exclusive of snow removal units, there is a practice of assigning one truck, usually in the 2.27 to 2.72 metric ton (2-1/2 to 3 ton) class for each 64.37 lane kilometer (40 lane-miles) of highway and interchange maintained. A pickup truck usually is assigned for use by the foreman and for patrolling the section for emergency removal of debris from the traveled way or other emergency use.

The use of two-way radio communication for maintenance management is almost universal. Only two states indicated that radios were not in use in maintenance equipment.

For replacement of equipment, two methods seemed to be most frequently employed. The first merely established a criterion of age, mileage or both, for the several classes of trucks and passenger cars. The age and mileage factor varies from state to state, but is generally expressed in number of years in use or number of miles operated, whichever comes first.

The second method of determining time for disposal of cars and trucks is on the basis of age, mileage, condition, and expert opinion of the equipment personnel, or some combination of these factors. Cost records are generally consulted as a further basis of decision. In this method, a determination is made for each individual car or truck under consideration. The evaluation is done by personnel in the district or division and reviewed at the central office level.

The evaluation method for replacement of equipment is used quite generally for maintenance equipment other than passenger cars and trucks. However, there is great variation in the availability, accuracy, and use made of operation cost records for equipment.

Equipment use on maintenance work generally is charged to the maintenance fund through a system of rental rates established on a statewide basis. Rates are based on time used or kilometers (miles) operated. The items used in the makeup of rental rates usually include: depreciation, direct operating cost, direct repair cost, indirect repair cost and expendable parts costs. Salvage value and other items, such as insurance premiums, also are given consideration in a few states.

There is considerable variation from state to state in the way in which rental time is determined. Time for which equipment charges may or may not be made include:

- Equipment in preparation for work:

  - Cleaning, fueling, adjustments
  - Moving to point of dispatch (mobilization)

- Equipment in transit from dispatch point to job site:

  - Short distances to job site
  - Long distances to job site

- Operating time:

  - Field standby time between several jobs
  - In transit from job site to job site

- Downtime for servicing or repair on the job:

  - Maintenance servicing
  - Field repairs

In a number of states, special maintenance equipment is designed, assembled, and placed in service by maintenance equipment shop personnel. However, too often the development of useful devices is not passed on within the organization so that the improvement may receive the fullest use.

There are snow removal vehicles and there are conventional trucks fitted with snow plows. The two are not necessarily the same [133].

In selecting equipment for snow removal, the vehicle should, if possible, be selected with its major end use in mind. If it is snow removal, then the vehicle should be classified as an emergency vehicle in that it should reflect an ability to perform efficiently and reliably.

In a conventional truck, gross vehicle weight is the yardstick used to classify the vehicle. Snow removal vehicles cannot realistically use this figure for total evaluation. Horsepower is related to GVW and is the measure of the ability of a vehicle to overcome grade, rolling, and wind resistance as well as move a load over a comparatively flat, dry surface. GVW is the load-carrying capacity of the vehicle in question and has little relation to snow removal capability.

Snow removal vehicles may not carry weight, but move a load by displacement. The weight of the vehicle is important; so is axle capacity. But, these must be translated into tractive effort, or that ability to exert a forward pushing force by the tires against the ground.

This is not to say that a snow removal vehicle cannot have a dual capability. Dump bodies which contain ballast during the snow removal season should be usable for general hauling during summer months. The only exception is the rotary plow, with its rear-mounted auger driving engine.

Four areas must be examined in the selection of any snow removal vehicle -- regardless of size or type. The first is the basic ability of the vehicle to move snow. Questions which must be considered are how much snow must be moved; in what time span; and at what speeds.

The second point which should be considered is that of reliability. Here, the total vehicle should be evaluated in those areas which see the greatest amount of stress in snow removal work. These areas include the frame, axles, transmission, clutch, transfer case, and differentials.

The third point to consider is that of durability. Snow removal equipment, as specialized equipment, represents a higher initial cost and the total life cycle of the vehicle becomes extremely important. If, by proper selection of equipment, additional years of service life are obtained, the overall cost may be reduced.

The final point, economy, has a relationship to durability, but also includes maintenance which can increase costs dramatically if additional equipment must be secured or maintained to keep traffic flowing.

A discussion of torque, or tractive effort, as opposed to selection by GVW alone, is the basis of selection of other frame and drive-line components. In a conventional truck, frame and axle components are selected on the basis of carried weight and the frame is designed accordingly. Drive-line components are selected then on the basis of horsepower to be utilized rather than torque loads to be absorbed.

When moving snow, forces are imposed on the frontal cross-section of the frame rather than on the top. In addition, side thrust from the use of a wing plow is imposed on the side of the frame at some distance back from the front of the vehicle. At no time is the full GVW rating of a vehicle used as would be the case if the vehicle were carrying a load. The only load carried is ballast, and that load is only that required to give weight on the driving wheels and approximately equal weight distribution on a 4 x 4 vehicle between the front and rear axles with the plow resting on the ground.

The important consideration is that the frame be designed to primarily take severe frontal-and side-thrust loads rather than carried loads. In addition, the frame must be designed to take shock loads caused by plowing into drifted snow. If a frame is designed for relatively constant loads, these shock loads may easily exceed design safety margins and shock loads will result in frame damage.

These same shock loads must also be considered in axle design. In an axle rated for a given GVW, design consideration is usually given to the load the axle must carry under intermittant torque loads. A snow removal vehicle is required to exert high hub-torques over a longer period of time.

Additional attention should be given to suspension design. In a conventional vehicle, suspension attachment components are of that weight and design required to support a load. Roads are fairly level and the suspension is rated on a carried GVW basis. In snow removal applications, suspension attachment components again must be strong enough to transmit high torque, side thrust, and shock loads through the springs to the frame.

In some removal vehicles with rotary plows attached, forward speed of the vehicles is generally slow, but engine rpm must be kept high for efficient engine operation and pushing the plow into heavy, drifted snow.

Engine cooling and radiator selection is another feature which distinguishes a snow removal vehicle from a conventional truck. A radiator may be sized for a conventional truck on the basis of heat rejection and ram air effect of a fast moving vehicle, and perform quite well. However, that same radiator will be obstructed by the plow in a snow removal application with reduced natural air flow.

An oversized radiator (if an over-the-road use is the basis for design) is therefore an asset in snow removal applications and not necessarily an added expense.

Types of plows, loaders, rotaries, melting equipment and spreaders available specifically for snow and ice control are summarized in the 1975 Public Works, Street and Highway Manual [134].

States, including Utah and California, have found it economically feasible to manufacture their own snow plows for snow and ice control. The benefit of swinging plows, if desired (by hand or hydraulic) can be incorporated into the design. Also, truck coupling mechanisms can be deployed as an integral part of the plow; such as shear bolts, trip-over mechanism, etc.

Washington State Department of Highways in 1974 evaluated the use of rubber snow plow blades [135] and found them to be an effective and economical tool to use during snow plowing operations, both for removing fresh fallen or slushy snows and for protection of raised traffic markers. Washington reported the rubber snow plow blade to be most effective when temperatures are near or slightly above freezing. The use of chemicals to create a slushy or thawing condition increases the temperature range in which the rubber blade can be used effectively.

Where ambient temperatures are consistently below freezing, the build-up of ice and compact snow on the roadway becomes so hard and tightly bonded to the roadway surface that the use of rubber snow plow blades becomes ineffective.

The optimum downward pressure on a 3 meter (10 ft.) rubber blade is approximately 317.5 kilograms (700 lbs.). This can be achieved either by by use of a light-weight plow or by modifying standard plows to relieve some of their weight. Weight distribution must be as even as possible along the blade length for effective operation and to control the blade wear.

The optimum blade exposure is 5 to 6 centimeters (2 to 2-1/2 in.). Less exposure slightly increases the blades ability to cut, but is believed to be more destructive to the blades and roadway surface. More exposure gives a tendency to roll under or slide over the snow instead of removing it.

Plowing snow with a properly adjusted rubber blade can be accomplished effectively at speeds ranging from thirteen to 40 kilometers (8 to 25 mi.) per hour.

In 1966 rubber-tipped snow plow blades were tried in Toledo, Canada for the division of harbors and bridges [136]. Goodyear noted features of the blades as: long lasting, no gouging or roadways, quick and clean removal, safe high-speed runs, less equipment shock, and lower maintenance costs.

During the Toledo evaluation, about one-third of the snow occurred at around freezing temperatures (-4 to -1°C or 25 to 30°F) where it is possible to take advantage of the "squeegee" effect that results from rubber-tipped blades with the result that we are salting as close to the roadway as possible with greater effect. They also allow for a faster and safer plow operation.

Results indicated that downtime due to plow damages is greatly reduced. Also, with the temperature conditions in Toledo, the salt usage was also reduced.

As a result of using the rubber snow plow blades, the truck drivers are experiencing less fatigue as they had been before their use; however, initially the reaction to using rubber tipped blades by the field personnel was that of reluctance, which is probably the main reason for their limited use.

A cost analysis of using rubber tip blades versus steel blades [135] showed the rubber to be up to six times less expensive than the steel. The use of carbide blades was found to be more cost effective than rubber [137].

Typical types of equipment presently used for snow and ice control are summarized in Table 25.

TABLE 25: TYPICAL TYPES OF EQUIPMENT PRESENTLY USED FOR SNOW AND ICE CONTROL

- Trucks: (23,000 to 39,000 GVW Rating)
  - Single Axle Dump or Hopper Bed
  - Tandem Axle Dump or Hopper Bed
  - 3 Rear Axle Dump or Hopper Bed

- Plows: (Rubber, Steel, Carbide Tipped)
  - Front Mounted V Type
  - Front Mounted Reversible or Fixed
  - Side Mounted Wing
  - Underbody Mounted

- Sanders: 2.29 M^3 to 9.56 M^3 (3 to 12-1/2 Cu. Yd.) Engine or Hydraulic Driven
  - Hopper (Fixed or Insert)
  - Tailgate

- Loaders: (All Sizes)
  - Front End (Track or Pneumatic Tire)
  - Backhoe
  - Belt Type

- Miscellaneous:
  - Pickup Truck
  - Rotary Snowplows Rotary Attachments
  - Snow Blowers
  - Graders (May Include Wing Plow)
  - Crawler Tractor
  - Dozers

Many states manufacture equipment for specific needs and modify existing equipment, again to better mesh with specific needs.

Existing practices in establishing rental rates for equipment may include items such as: depreciation, purchase cost, repair and maintenance, insurance, fuel, accessories, and various types of overhead. These are not pertinent to states other than to themselves, in that the cost basis is not necessarily the same from state to state.

Minnesota uses a specific approach that allocates equipment based upon a need formula. In essence, the required number of single and tandem axle dump trucks is directly related to lane mileage, number of interchanges and cycle time. The criteria used in this process are as follows [138]:

- Average net plowing speed of 24 kilometers (15 mi.) per hour (based on total operating time). The net plowing speed is based on the standard time for one man plowing operations.

- Cycle time for interchanges increases to 1-1/2 times the cycle time for the adjacent mainline. This criteria can be satisfied by providing one truck for each:

  i) 1-1/2 urban complex interchanges
  ii) 2 urban simple interchanges
  iii) 4 rural simple interchanges

The procedure for determining the number of trucks required employs the equation

$$N_t = \frac{D}{15C} + \frac{N_{A_u}}{1\text{-}1/2} + \frac{N_{B_u}}{2} + \frac{N_{A_r}}{2\text{-}1/2} + \frac{N_{B_r}}{4} \qquad (18)$$

where

N_t = number of trucks required
D = distance to be plowed in lane miles
15 = average plowing speed in miles per per hour
C = cycle time in hours
N_{A_u}, N_{B_u}, N_{A_r}, and N_{B_r} = the number of complex (A) and simple (B) urban (u) and rural (r) interchanges

Underbody snowplows have been used successfully in Michigan's efforts at snow and ice removal. Here higher speeds have been obtained in plowing snow. One advantage to their use in Michigan has been that the underbody plows do not have to be removed for summer maintenance operations and fewer chemicals are required to remove ice and hard pack snow from the pavement surface because a downward pressure may be applied.

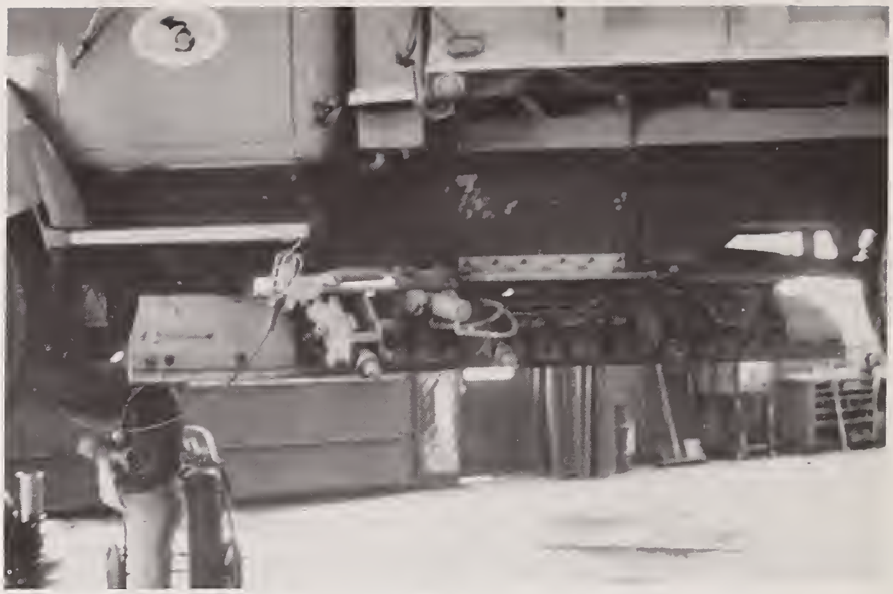


FIGURE 73: UNDERBODY SNOWPLOW ON HOIST FOR INSPECTION (Courtesy Michigan Department Of Transportation)

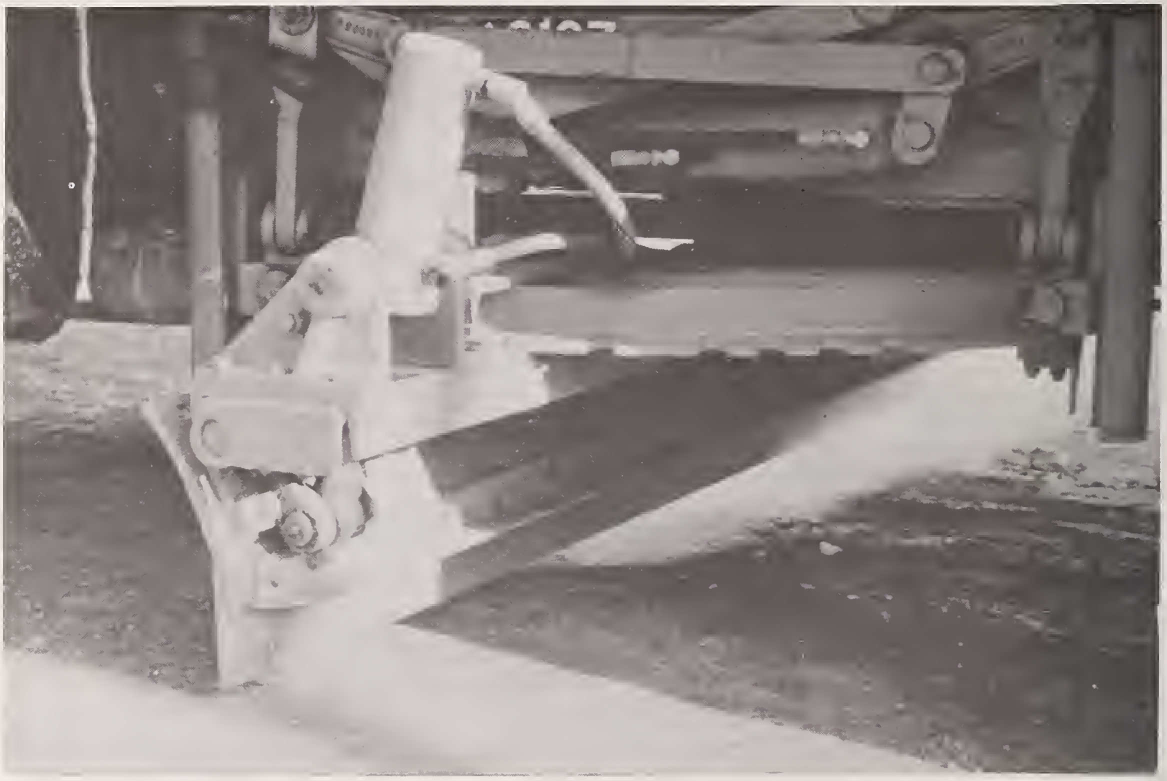


FIGURE 74: UNDERBODY SNOWPLOW CLOSEUP (Courtesy South Dakota Department Of Transportation)

Equipment costs have been reduced for states where the most is made of the ability to assign equipment a dual usage function. Total inventory of equipment can be kept to a minimum, thus support costs of storage and unit equipment maintenance are also kept to a minimum. There are two fundamental approaches to the use of trucks in snow removal operations. The first is to think of trucks as emergency vehicles in that they are kept in prime operating condition for the one function they were purchased, to perform snow removal, and none other. The second is to think of them in terms of a significant dollar investment which should be yielding continuous returns, not only in their prime winter maintenance operations but in other functions the year round.

A number of trucks in Otsego County, Michigan [193] are fitted with snowplows and underbody blades, a cross between a motor grader and a highway truck. On one truck is installed portable concrete block weights over the fifth wheel during plowing operations. In the summer this vehicle is used to pull lowboys and haul construction equipment.

Another practice that reports cost savings adopted by Idaho [163] is to purchase trucks that are of one make vehicle for an entire fleet [133]. Roy Jump reported "tremendous dollar savings to Idaho by drastically reducing the stock of parts in the warehouses."

Closely related to dual usage of equipment is the practice of shifting equipment from one location to another depending on work demand and time of year. This method of optimizing equipment usage can be practical if the agency has significant differences in equipment demand between stations during various seasons of the year. In locations where a vast area must be covered and differences in the type of equipment are needed for the various kinds of snow conditions, it becomes difficult to shift equipment from one location to another.

To facilitate the use of mobile equipment, E. J. Kehl in Illinois issued a memorandum in 1973 which reads in part:

> *In the past winters there have been occasions where reluctance to request assistance on the part of a district experiencing an extraordinary localized storm or blizzard has put that district in the position of "digging out" rather than "getting on top of" a storm. Under current staffing, it is imperative that every effort be made to use those resources that are available over the broadest range during periods of peak demand.*
>
> *In preparation for severe storm situations, each district region is being asked to develop a team of reliable, compentent maintenance men, equipment operators and foremen who are generally in agreement and who can be assigned away from their homes occasionally for several days without undue hardship on their families.*

Personnel

Manpower requirements for snow and ice control must be established in accordance with overall needs of the maintenance function and usually cannot be isolated and reviewed independently. Difficulty in establishing in advance, the hours required, the productivity per storm and frequency of storms as compared to most other maintenance activities makes optimizing labor for snow and ice control ambiguous. For these reasons, no significant works have been undertaken to identify manpower needs, especially in a public service activity of this type, unlike an activity that is production line or manufacturing oriented.

Therefore, this chapter attempts to highlight selected states procedures regarding management of employees, total labor costs in relation to other costs, overtime, overhead and the relative cost effectiveness of unions. With an acute awareness of the percentage of snow and ice control funds that go to labor, possible procedures used in management by different states can help others to utilize present manpower resources more efficiently.

Personnel training is one method of improving the efficiency of employees.

Maintenance employees typically feel a keen obligation to the traveling public, including a kind of "esprit de corps" that comes only with training and experience [141]. Proper training for maintenance personnel is vital. It gives people the know-how to get the job done, encourages performance in a way that brings praise rather than discredit to your organization. Adequate training should ensure:

- Equipment operators fully understand how to operate and maintain plows, spreaders or loaders.
- That all employees are thoroughly familiar with their responsibilities.
- That all employees receive a full review of snow removal schedules, describing the beginning and end of each section and personnel and equipment assigned.
- That dry runs are made over areas to be covered during actual snow-fighting operations.
- That all employees understand how deicing materials work to melt or combat ice so they know how and when it is best applied.

Training of personnel should include lectures and practice sessions (operations) to familiarize all personnel with planned operations: the geographical areas to be covered; the problems to be expected; the desired results from each workman and crew. (Question and answer sessions may prove beneficial). Also, part of this training should include discussion and guidelines for discipline and courtesy toward the motoring public.

In fall training sessions, discuss each type and class of equipment men will operate. Go over the strengths and weaknesses of each. Describe performance capabilities, load and weight limits, specifications, safety considerations, attachments and modifications.

If possible, assign each operator to a specific piece or combination of equipment. Man and machine make a better team when they work together consistently. The feeling that a vehicle "belongs" will make an operator show more responsibility for its upkeep.

In large organizations, it may be necessary to switch operators from one piece of equipment to another. Then you must depend on a system of checks to insure that equipment is properly operated and maintained.

A session on snow and ice removal well ahead of winter provides a chance to discuss plans with the people expected to carry them out.

Promote give and take at the fall meeting. Encourage all personnel to speak up. New ideas and better tactics can come out of this session.

One key to proper shift arrangement is the amount of snowfall and its duration [140]. Generally, if the typical duration of a storm is ten to twelve hours a suitable shift arrangement may be obtained by calling operators in as they are needed after normal working hours. If the storm duration is typically fifteen hours or more, an alternate shift arrangement might be best. One such arrangement is made by splitting the normal staff in half at the start of a severe storm and establishing two, 12 hour shifts.

In areas of intense snowfall and prolonged snowstorms it may be advantageous to retain the splitshift as the normal arrangement during the winter months. Use of this splitshift arrangement requires dependable weather forecasting sources.

Selected practices of selected states in combating snow and ice are provied in the Appendix. (Page 208) Annual publications [192] provide data on various states' staffing for highway maintenance and their breakdown according to worker, foreman, etc.

CHAPTER IV

TRAFFIC AND SAFETY

by: Bob H. Welch, Roger M. Stewart
Dr. William J. Kennedy

Introduction

A significant effort in terms of both manpower and financial resources is expended annually by the several levels of government on snow and ice control programs [153]. Justification for these large expenditures, which are as high as 33 percent of highway maintenance budgets on environmental weather conditions that exist only four to eight percent of the year, has traditionally been granted through improved road user benefits. The most common road user benefits claimed have been increased safety and decreased traffic delay, particularly in urban areas. These benefits are the most easily recognized and are apparent immediately during snow conditions. Changing the level of service or level of effort for snow and ice control have immediate and sometimes measurable effects on delay, altered traffic volumes, traffic congestion, public acceptance and newscast attention. After a storm impact period, the return to normal traffic flow conditions is relatively soon compared to the impact recovery time for bridge decks, highway appurtenances vehicle corrosion, the environment and alternations required by maintenance departments. It has traditionally been assumed that the economic effects from snow and ice control practices to non-road users are negligible compared to those experienced by road users. In terms of benefits, this is probably true. A study undertaken by the American Public Works Association [142] to formulate a methodology for snow and ice control, resulted in a marginal analysis which permits the comparison of the economic merits of varying levels of expenditures for ice and snow removal. All of the potential benefits to a community were examined before developing the analysis, but as finally outlined, the major benefits were attributed to the road users.

In reality, there are many savings in vehicular operating costs produced by improved highways through higher levels of snow and ice control. For automobiles, such savings are generally converted to time savings by driving at increased speeds with a probable increase in fuel and tire costs [143]. Time savings or time losses associated with snow and ice maintenance may be valued within a marketable concept and should not be handled in the same way as tangible costs or savings such as fuel consumption. Measurements of the value of time must always be averages, and generally rather unstable ones [143].

Time has different value to different persons, and to the same person on different occasions.

> *It is also held, and generally acknowledged, that minute time savings are of less unit value than time savings of considerable amount. For a million persons to save one minute out of an hour's trip does not, so it is said, produce the same dollar savings as 100,000 persons making a 10-minute savings in an hour. While the truth of this proposition seems obvious at the extremes, there is some evidence that many motorists behave as if minute time savings were a major objective. The active and aggressive driver continually tries to pass the cars ahead of him, although the net result may be only a few minutes or a few seconds saved in a trip of considerable length* [143].

Road user benefits from snow and ice control activities may justify present or accelerated expenditures but the relationships between road user benefits and expenditures need to be defined in much greater detail than is currently available.

In this chapter, a review of work that has been undertaken to quantify road user benefits from snow and ice control is presented. Road user benefits reviewed represent safety characteristics, delay, tardiness, absenteeism, production or manufacturing loss, convenience and comfort.

Reduced Volumes

The interaction between people and space has been studied by economists, demographers, sociologists, planners and others. Many factors affect the movement or interaction of persons and things in space. The various factors can be categorized as; a generating factor related to the individual trip-maker and his willingness to travel, an attraction factor related to the importance (or utility) of the particular destination, and a linkage factor related to the difficulty (or cost) of moving from the origin to the destination [144].

Traveler behavior relates to descriptions and understanding of how, and in response to what, travelers believe. A considerable body of theoretical and empirical knowledge or belief on the subject already exists [145]. For example, one economic theory of travel behavior considers most travel to be an intermediate good that must be consumed at some monetary and psychological cost to the traveler in order to derive equal or greater benefits in kind from activities indulged in at the trip destination. The response of travelers to travel cost and destination opportunity "choices" will vary depending on the characteristic of the behavioral units. Definition of the attributes of the choices in terms of appropriate transportation system costs and destination opportunities and a definition of appropriate behavioral units are yet to be made.

In particular, the decrease in traffic movement generated as a result of adverse environmental conditions is virtually unexamined. In analyzing certain characteristics of accident rates, the notion of reduced volumes related to numbers of accidents is only mentioned for snow and ice conditions; the identification or attempt to identify how severly traffic volumes are reduced has not been undertaken.

Economic anlayses associated with snow and ice conditions do not take into account the reduction of vehicle volumes caused by destination opportunities not attractive enough to warrant generation of the trip. This omission may significantly affect economic analyses.

Traffic volumes on individual roadway segments do not always decrease since some people alter normally chosen routes when traveling on snow or ice covered roads. Particularly in urban areas where route alternatives are available, the motorist often chooses new routes not normally taken, thus affecting any economic analysis using ADT values for traffic volumes.

Safety

The general assumption has always been that snow and ice on highways causes accidents. There are a number of reasons for this assumption. Ice and snow reduce the coefficient of friction between the pavement and automobile tires making maneuvering of the vehicle very difficult and occassionally impossible. While snow is falling, visibility can also be severly reduced. Ice is not always apparent to the motorist and is not uniform so that the driver is not always prepared when he encounters an icy section of roadway. Preferential icing of bridge decks can be especially dangerous due to the drivers' possible unawareness of the situation.

The factors would seem to strengthen the argument that salt saves lives. Unfortunately, the actual degree to which these factors influence safety is unknown. Also, there may be some positive safety aspects of snow. During heavy snow, traffic is reduced severely; possibly reducing the total number of accidents even though the accident rate may be higher. This reduction in traffic can cause a great reduction in mobility and subsequent economic losses.

The American City Magazine conducted a survey of cities on the subject of the use of deicing salt [146].

Two of the questions asked in the survey related snow and deicing salt use to accidents. One question asked: how many accidents occurred on snow-covered streets versus streets treated with deicing materials? Of the fourteen cities that provided responses, all had a high percentage of accidents occurring on untreated streets. These figures, however, cannot be considered conclusive since the sample size is small and the range of percentage of accidents on these roads changes during normal conditions or what the traffic distributions are during inclement and normal weather conditions.

The Environmental Association of Otesego and Delaware Counties (State of New York) conducted a study of the effects of deicing salts on safety and the environment using existing accident records from various county and state records [147]. These records were divided by location, high and low salt usage areas and compared on the basis of safety. This report concluded that an accurate determination of the safety effects of deicing salts could not be made using the data available. The data did show an increase in accidents during the winter months and a less substantial increase in accidents in townships using deicing salts. But the data available does not take into account the other variables that can affect accidents such as traffic volumes, traffic distributions and actual weather conditions.

According to the National Safety Council's "Accident Facts," there has been no change in the proportion of all crashes, including injury and fatal crashes occurring on snow-or-ice-covered roads from 1956 to 1970, despite the several-fold increase in total salt usage of 33 states using deicing salts, since 1956 [148].

The extent to which highway accidents have decreased in response to engineering improvements has not been properly accounted for as regarding (a) improvements in the design of automobiles, (b) improvements in tire quality and efficiency, (c) improvements in driver performance resulting from expanded driver education programs, and (d) improvements in highway design, engineering and construction [149]. Salt spray splashed on an automobile windshield may create a semi-opaque white film which can substantially reduce visibility [150]. Many of the safety benefits to be derived by the highway users may also be enjoyed by the maintenance crews when they are performing their work [151].

Preferential icing of bridge decks, a well-known safety hazard, refers to the formation of ice on a bridge deck at times when the approaches become merely wet or even dry. The accident potential (safety hazard) is thought to be very high because it represents a local hazard that traffic encounters without warning under otherwise normal conditions. Obviously, economic considerations dictate different solutions when counter-measure is likely to be used only once a year or when it is needed frequently, or when the skidding accident experience is high because of either traffic density or road geometry [152].

The important traffic problems associated with snow on roads are caused by decrease of visibility, the difficulty of snow removal work, and the slippery conditions of the road surface. Powder snow remains in the air for a long time after a car has passed by making visibility poor. Drivers of following cars have trouble seeing the direction of the road [153].

The American Public Works Association [154] evaluated the effect of snow storms on accidents in Chicago and reported;

> *It should be noted with regard to storm-related accident costs that while a more severe winter will generally result in a higher incidence of accidents, this relationship does not always apply to specific storms. The worst storm for accidents in the winter studied was a half-inch [about 1 cm] storm on a Friday, although there were a number of heavier storms on weekdays. In very heavy storms, traffic volume may be sharply reduced and the total number of accidents lower than normal. Nevertheless, the accident rate will usually be significantly higher. Generally, however, the total number of accidents on urban streets rises sharply during and immediately following winter storms. It is interesting to note how the severity varied in the accidents studied. During a snow storm, almost one out of three accidents results in a personal injury (including fatalities) when the pavement is wet, but only one out of ten results in personal injury if the pavement is covered with snow. The ratio is two in ten for clear weather and dry pavements. In clear weather the same situation prevails, severity is up on wet pavements and lower on snowy pavements. This seems to indicate that the driving public is aware of the danger of snowy and icy streets and slows down, but is not sufficiently aware of the loss of traction on wet pavements.*

California [155] reviewed accidents while studying their bare pavement policy. Accident experiences were evaluated for three fiscal years. This report concluded:

Accident rates for snow and ice conditions could not be determined because the information quantifying the time of winter weather and when snow and ice were on the pavement was not available. Therefore, the accident data was retrieved from the computer in two groups: group one included accidents with snow and ice on the pavement, and group two, accidents with no snow and ice on the pavement.

Due to the large number of highway routes and accidents the analysis was limited to the routes in highway districts with the largest amount of snow and ice removal expenditures. The highway routes were classified according to their 1973-74 winter ADT and the number of accidents with snow and ice on the pavement were analyzed.

This analysis indicated that highways with 1973 winter ADT's below 800 had very few accidents. This would imply that accidents would not be considered a factor in the review of snow and ice removal policies for these highways. Even with winter ADT between 800 and 2000, the number of accidents is within an "acceptable range." However, there are exceptions, where the weekend ADT is greater than 2000. Approximately 50% of the accidents occur during that time. These routes' primary function was to service skiing areas. In the portion of the study evaluating highways with an ADT greater than 2000, the following was noted:

- Accident rates for 1973-74 dropped noticeably from the 1972-73 ratio due to the energy crisis and less travel and also the reduced, 90 kilometer per hour, (55 mile per hour) speed limit.

- Accidents increased with an increase in ADT for similar roadways.

- Higher accident rates were noted at approaches to vertical summits.

- Higher accident rates were noted on sections of highway with substandard geometrics.

The California investigation noted that a snow belt crosses Route 5 from approximately Dunsumir to north of Weed west of Mount Shasta resulting in snow storms up to forty-one centimeters (16 inches) in depth and seasonal depth up to 380 centimeters (150 inches). This is the section where most of the district's snow problems occur and result in the highest winter accident rates. The remainder of Route 5 has an average snow storm depth from ten to twenty-five (4 to 10 inches) with a seasonal depth of from 30 to 130 centimeters (12 to 52 inches). Portions of Route 50 were also analyzed for safety yielding the following: Traffic on Route 50 has continued to increase at approximately five percent, even with the energy crisis. The four-lane freeway and expressway sections of Route 50 had an average accident rate excepting for the portions through Placerville and South Lake Tahoe with its urban-type development and the section with substandard geometrics from the Sly Park Interchange to Riverton. The two-lane section from Riverton to Meyers via Echo Summit is affected by high volumes of traffic (especially on weekends) substandard geometrics, 1,150 centimeters (450 inches) of seasonal snowfall, high elevations, and steep grades, resulting in winter accident rates as much as 5.5 times the summer rates on the same section of roadway. Accidents could be a factor if the level of service on this route was reduced.

One study by the Ohio Department of Highways showed that 35 percent of all rural traffic accidents occurred while roads were covered with snow and ice, although there were less than seven full days that winter when roads were snow-covered. The loss in property value was approximately three million dollars. It was projected that without the use of snow plows or deicing chemicals, snow and ice would have remained on rural Ohio roads for more than 40 days causing 22,700 accidents and resulting in $14,500,000 in property damage, plus more human suffering and many deaths. In Chicago, the Citizens Traffic Safety Board reported that a snowfall of less than one centimeter (half-an-inch) brings an accident rate ten times that for the same hours when pavements are dry. According to the board's study, Chicago's salting program prevents 15,250 accidents a year that would cost victims more than $3.7 million. In 28 percent of those accidents, someone would be injured or killed.

It is sometimes argued by critics of deicing salts that because drivers tend to drive more slowly and cautiously during hazardous icy conditions, the injury and mortality statistics would be lower than for bare pavement conditions where drivers tend to drive faster. This rationale ignores the fact that bare pavement offers better traction and, therefore, safer road conditions, and it is the driver rather than the bare pavement that constitutes the hazard.

Studies on highway accidents are usually geared towards highlighting hazardous locations for prioritizing improvement projects [156-165] and [166]. Thus total numbers of accidents, type of accidents, environmental conditions, date, etc. are recorded surrounding each accident. For a given highway segment or network, no information has been collected regarding the total vehicle miles driven for the corresponding adverse environmental conditions. Therefore, a comparison of the number of accidents for dry versus wet versus snow or ice pavements does not, by itself, demonstrate an increase or decrease in accident rates.

Fuel Consumption

Fuel consumption costs are directly affected by snow and ice control policies.

Fuel consumption rates by automobiles, trucks, homes, etc. have been studied extensively for normal conditions and adjusted to account for availability, price and weather (temperatures) [167]. For vehicular gasoline consumption as it relates to adverse highway conditions, the only work available is that by P.J. Claffey [168] and [169]. In his articles, a comparison of fuel consumption between dry pavements and ice and snow covered pavements is presented. Mr. Claffey studied the effects of road surface ice, hard-packed snow, and various depths of newly fallen snow on the fuel consumption of a typical passenger car during the winter of 1970-1971 on a straight, level test road near Ogdensburg, New York. Data on operation under various conditions of ice and snow were compared directly with data from dry road operations. The results given in this paper include the rate of fuel consumption of the typical passenger car in relation to speed for each of the ice and snow conditions involved in the study, the straight-line relationship between the fuel consumption of the typical passenger car and depth of newly fallen snow for three running speeds, and the factors to correct dry pavement fuel consumption rates for the different ice and snow conditions for the various speeds. The worst ice and snow condition as far as fuel consumption is concerned is snow depth. Fuel consumption will be 50 percent more on a road with a five centimeter (two inch) snow depth than on a corresponding dry road [168].

Ice and snow conditions restrict vehicle movement in a variety of ways, depending on the actual condition of the ice or snow on the pavement. Both ice and snow, but particularly ice, cause excess fuel consumption by including slippage of the traction wheels, which in turn produces engine revolutions without corresponding vehicle movement. Both ice, when it freezes into shallow ruts, and snow, which packs down into a rough wash-board-like surface, present an irregular running surface for vehicles. This wrinkled surface causes vehicles to consume extra fuel because they must continually climb over these irregularities to produce forward movement. Freshly fallen snow of two and a half centimeters (one inch) or more in depth also increases vehicle fuel consumption because of the effort needed to pack down the snow under the wheels as vehicles move along and the necessity to climb over and across ruts left by other vehicles. All ice and snow conditions involve considerable side throw of vehicles at speeds above 50 kilometers per hour (30 miles per hour). This also adds to vehicle fuel consumption.

The test car was a 1964 Chevrolet sedan with a 4,638 cubic centimeter (283 cubic inch) V-8 engine and automatic transmission. It weighed 1,814 kilograms (4,000 pounds) during test operations with all test personnel and equipment aboard. This vehicle was the principal passenger car used in the operating cost study reported in a NCHRP report [169]. Engine performance was satisfactory. The engine consumed fuel under ideal test conditions at the time of the snow study (winter of 1970-1971) at about the same rate that it did during the 1964-1967 period when it was used for obtaining the data for the NCHRP study. Snow tires of a good grade that had previously been used for 8,050 kilometers (5,000 miles) of winter travel (typical wear of snow tires) were mounted on the traction wheels for this test program.

The relationship between fuel consumption rates and vehicle speeds for passenger car operation on roads with the various ice and snow conditions are illustrated in Figure 75. Curve A represents the fuel consumption for the test vehicle operating on dry pavement. Data for this curve were obtained by operation at ambient temperatures higher than those encountered during the ice and snow test conditions (40°F compared to 25°F to 30°F). Test operations were carried out at speeds up to 95 kilometers per hour (60 miles per hour) on bare pavement, on ice-covered roads, and for snow depths up to one and one-fourth centimeter (1/2 inch). However, for snow depths greater than .85 centimeter (1/3 inch), maximum test speeds were limited to 80 kilometers per hour (50 miles per hour) largely because of the severe side throw drivers encountered in deeper snow when traveling at high speeds.

The excess fuel consumed for stop-and-go cycles on very slippery, hardpacked snow and ice (condition 1) was found to be 0.03 and 0.06 liters (0.008 and 0.017 gallons) per stop at 50- and 80-kilometer per hour (30- and 50-miles per hour) running speeds respectively. These values are close to those observed for stop-and-go cycles on dry pavement; 0.04 and 0.06 liters (0.010 and 0.017 gallons) per stop. However, the excess time consumed for stop cycles at 50 and 80 kilometers per hour (30 and 50 miles per hour) are approximately 50 percent greater on ice- and snow-covered pavement than on dry pavement. Apparently, any extra fuel consumption due to slipping on the ice during the

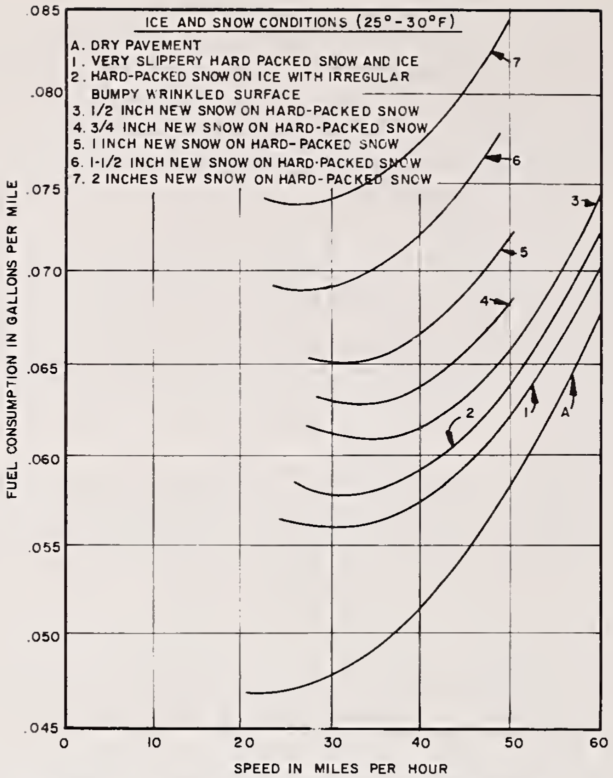


FIGURE 75: FUEL CONSUMPTION RATES OF A PASSENGER CAR FOR VARIOUS ICE AND SNOW CONDITIONS (168)

acceleration portion of the stop cycle is compensated for by reduced consumption due to lower acceleration on ice.

The curves of Figure 75 show that the ice and snow condition having the most severe effect on passenger car fuel consumption is newly fallen snow. Even as little as one and one-fourth centimeter (1/2 inch) of snow (curve 3) will induce fuel consumption rates greater than either a very slippery, hard-packed snow surface (curve 1) or a less slippery, but bumpy, wrinkled surface (curve 2). Curves 3, 4, 5, 6 and 7 give the fuel consumption rates for road conditions that are identical except for snow depths, which are 0.81, 1.91, 2.54, 9.68, and 5.08 centimeters (1/2, 3/4, 1, 1-1/2, and 2 inches) respectively. It is evident from Figure 75, however, that all roads with ice or snow or both, whether principally slippery, rough, or snow-covered, produce a substantial increase in passenger car fuel consumption compared to operation on dry pavement.

The curves of snow depth versus passenger car fuel consumption for 50-, 65-, and 80 kilometer per hour (30-, 40-, and 50-miles per hour) running speeds are illustrated in Figure 76. These curves indicate that the effect of snow depth on fuel consumption increases with increases in speed. The principle reasons for this increase are the side throw and rough handling experienced by drivers traveling at high speed over the ruts left in a fresh snowfall by other vehicles.

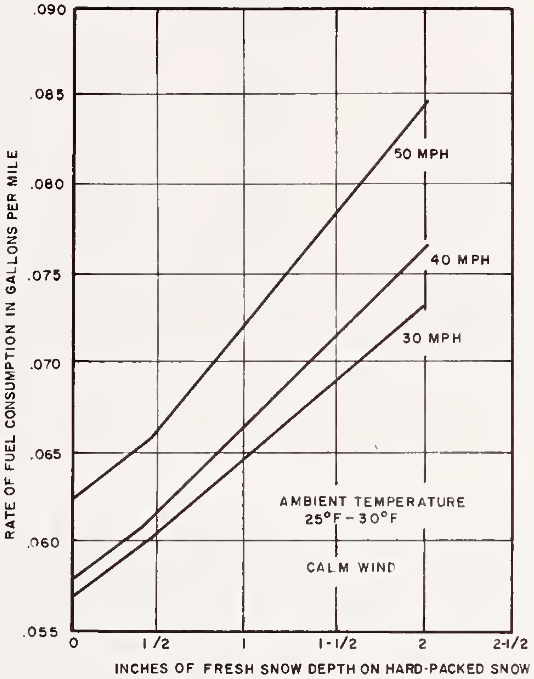


FIGURE 76: RELATIONSHIP BETWEEN SNOW DEPTH AND RATE OF FUEL CONSUMPTION OF PASSENGER CARS (168)

Table 26 gives correction factors to adjust passenger car fuel consumption rates on dry pavement for operation when the road surface is covered with ice and snow. If the dry surface fuel consumption rate of a particular type of automobile (or of passenger cars in general) is known for travel on a road having given geometrics, the fuel consumption when the road is covered with any of a variety of snow or ice conditions may be found by multiplying by the appropriate correction factor from Table 26. Dry pavement fuel consumption rates should be corrected for temperature before applying correction factors for snow conditions [168].

TABLE 26: CORRECTION FACTORS TO ADJUST PASSENGER CAR FUEL CONSUMPTION FOR ICE AND SNOW CONDITIONS [168]

Speed (mph)	Dry Pavement	Very Slippery Hard Packed Snow	Hard-Packed Snow on Ice With Bumpy Surface	New Snow on Hard-Packed Snow (in.)				
				1/2	3/4	1	1-1/2	2
20	1.00	1.23	1.30	1.36	1.43	1.47	1.51	1.60
30	1.00	1.16	1.20	1.28	1.32	1.35	1.45	1.54
40	1.00	1.11	1.14	1.20	1.23	1.28	1.40	1.48
50	1.00	1.06	1.10	1.12	1.18	1.24	1.34	1.45
60	1.00	1.04	1.08	1.10	-	-	-	-

Note: Correction factors are designed to be applied to values in Table 6 of NCHRP Report 111. They may however, also be applied to any valid passenger car fuel consumption rates for operation on dry pavement.

Delay

Inclement weather conditions such as those resulting from snow and ice covered pavements increase the time of travel of motor vehicles on a given highway segment. The travel time during inclement weather must be compared to the normal time for a given highway trip. Normal trip times have been related to type of highway, volume and capacity ratios, sight distance, time of day plus many more variables [170]. The quantitative effects of snow and ice on increased travel times have not been precisely defined, although the corresponding economic value of the increased time delay has been investigated.

The economic value of time delay on a highway segment resulting from snow and ice is tempered by several variables, including; type of vehicles, normal time delays, trip purpose, time of day, and increased fuel consumption.

A detailed review of normal highway operating speeds is not included since this project emphasizes the change from normal operating speeds or times as a result of snow weather conditions. For a given highway segment or network, the evaluation of normal traffic flow conditions may be measured directly and does not have to be projected as would be the case when considering investments for highway improvement or construction projects.

From the APWA study [142], "storm speed factors" have been developed, and take into account duration of the storm, rate of snowfall, temperatures above or below -4°C (25°F) and total snow depth. Figure 77 illustrates impact of a 1 1/4 centimeter (1/2 inch) snow storm, above -4°C (25°F) at snowfall rates of 1.27, 0.42, 0.21

centimeter (1/2, 1/6 and 1/12 inches) per hour. These charts represent urban average speed factor reductions for the storm period.

In the "Urban Snow Hazard: Economic and Social Implications" [186], the APWA charts were used to evaluate costs of storm related traffic delays. The storm speed reduction factor was quantified by

$$SF = e^{-B}D^{T} \quad \text{where} \tag{18}$$

D = Accumulated snow depth.

B = Constant estimated from APWA graphs.

T = Subscription for indicating temperatures above or below -4°C (25°F)

One problem encountered [186] in interpolating the APWA graphs was that they were not labeled to allow the reader to tell what removal capabilities were assumed for each line. Therefore, it was assumed that in each figure, the line showing the longest and most severe disruption was based on zero removal effort by the municipality and reflected simply the natural removal occasioned by sun, air temperature and traffic.

Verification or repudiation of the APWA curves has not yet been documented, although the basic interactions between storm characteristics on traffic speeds is sensible, and these numbers should be considered only as estimates. Equation 10 also reflects the basic variable interaction. Ideally, the constants would be determined for the highway system being evaluated and not from average values; since the magnitude of time delay generated for a traffic flow stream is potentially very high. For comparative analysis on levels of effort to combat snow or ice in urban areas, the approach suggested by APWA could be used to its fullest advantage.

The value of time brought on as a result of increased traffic delays should be evaluated or adjusted depending on several variables, including the type of vehicles, urban versus rural highway and time of day. Research identifying how these variables are affected by snow or ice conditions is not available. For instance, these relationships have not been quantified: increased travel time for the percentage of trucks versus cars on urban or on rural highways, speed reductions before, during or after storms, night storms effect on daytime speeds and vice versa, accident and/or conjestion delay versus snow or ice delays.

The corresponding economic value of time, once storm delays have resulted, has been the product of many research activities. The Stanford Research Institute [172] estimates the values of travel time savings as a function of three factors: amount of time saved (the amount of time "Saved" is a commonly used expression, but it is a misnomer; time cannot be saved, it can merely be used in different

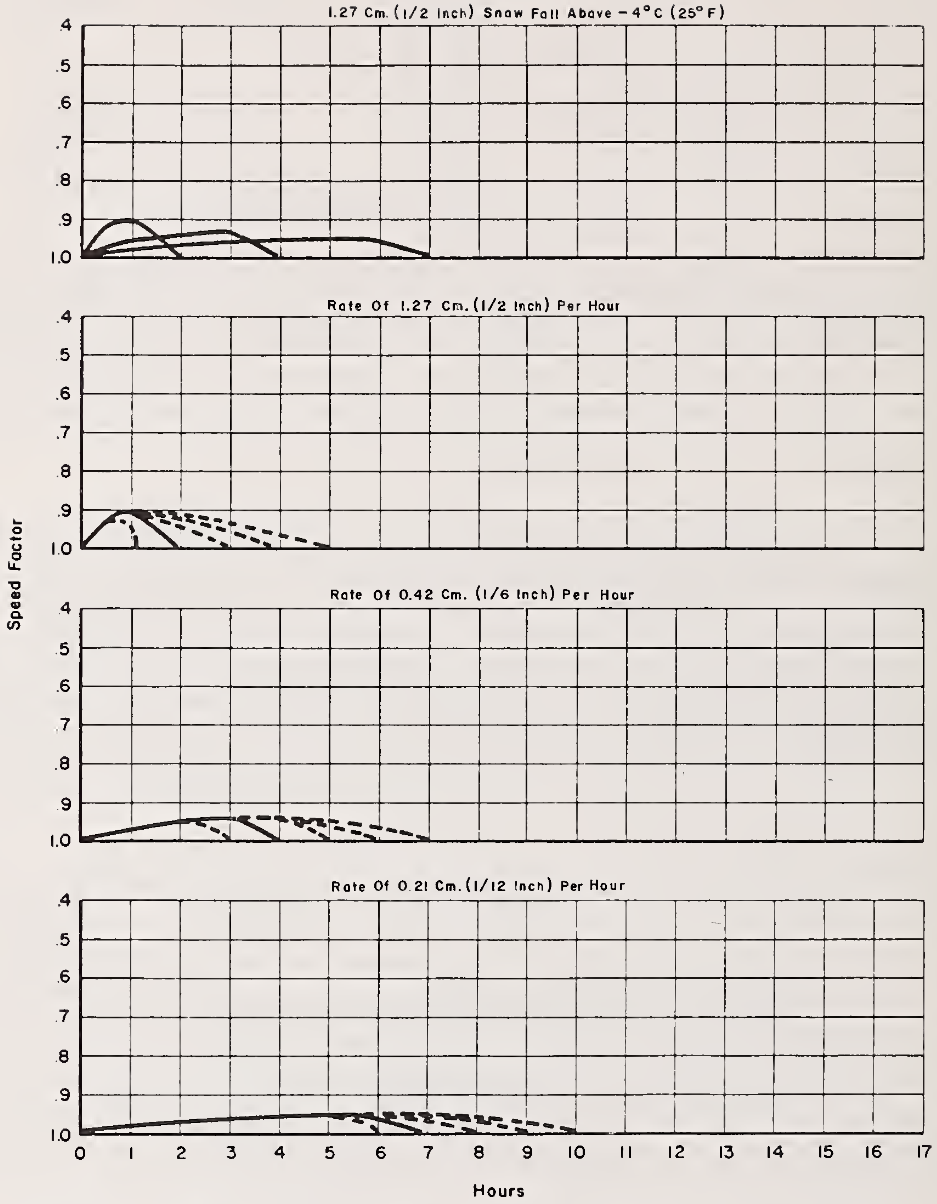


FIGURE 77: STORM SPEED FACTOR CURVES FOR 1.27 CENTIMETER (1/2 INCH) SNOW ABOVE -4°C (25°F) (142)

ways. Thus time saved in travel derives its value from the alternative uses to which it can be put), income level, and trip purpose. Such values of time savings are then converted into equivalent dollar values, which can then be compared with construction costs, maintenance costs, and other real or equivalent cost factors.

The estimated values [172] are a product of a series of studies by the Bureau of Public Roads, originating in 1962. The first study developed conceptual models which assign a value to the travel time saved by commuters on a particular highway segment [172]. Small-scale survey work and limited modeling were then completed. This led to a full-scale empirical attempt to estimate the value of commuter time. Thus, in 1968, an estimate of $2.82 per person per hour emerged as the value of time saved [172].

A single constant value of time, even for a single trip purpose, was only a first approximation to a more general variable value. Developed by Thomas, et. at. [172] are estimation techniques which indicate the value of time saved to be dependent upon both the motorist's income level and the amount of time saved. Further refinements were made at estimating time values by the SRI's report through accounting for the trip purpose other than work. Values of time have been estimated for personal business trips, social recreational trips, vacation trips, and school trips. Tables giving the SRI projected values of time savings as a function of these variables are presented in [172].

The value of time savings is also dependent upon vehicle type. "Values of Time Savings of Commercial Vehicles", NCHRP #33 [173], reviews and analyzes various methods that have been proposed for evaluating time savings that accrue to highway vehicles. It also develops a cost savings approach for determining the value of time savings and applies this approach for a composite cargo vehicle, a composite intercity bus, and a number of cargo vehicle types. They summarized [173] that an estimate of the value of time savings falls into four major categories.

1. Revenue (net operating profit) method. Assumes that time savings will be translated into additional revenue miles. The method uses the theory of the firm and has certain empirical advantages. Its weaknesses are the lack of knowledge of fixed versus variable costs in relation to time savings, the implied assumption that time savings generate additional gross revenues, and the difficulty of localizing revenue data.

2. Cost savings method. Assumes that time savings lead to a saving in resources required to perform a given volume of output. The method generally follows the theory of the firm, the principle of cost minimization, and has empirical advantages compared to the revenue approach. Greater localization of data can be obtained. The method's basic weakness is that too little is known about time-associated cost functions.

3. Cost-of-time method. Refers to the cost of providing time savings to highway vehicles. The method was conceived as a decision-making aid at the highway project level. The method does not measure the value of time in an absolute sense. Its strength is in its potential for alleviating the need for such a value.

4. Willingness-to-pay method. Attempts to assess the value of time in a market framework. The measurement may be through toll fees or in opportunity costs (utility or value foregone to attain time savings). Extrapolation to average values and the application of the method in general are quite complex. Secondary data for the approach are scarce and the generation of primary data appears to be difficult and expensive.

The recommended values of time savings per hour for composite vehicles, by ICC regions, are as follows:

TABLE 27: VALUES OF TIME SAVINGS COMPONENTS FOR COMPOSITE INTERCITY BUSES, BY ICC REGION (1962 DATA UPDATED TO 1965-66) [173]

ICC REGION*	VALUE OF TIME SAVINGS ($/HR.)							
	INTEREST S_1'	Depreciation S_2'	Property Tax S_3'	Driver's Wages S_4'	Driver's Welfare S_5'	Workman's Compensation S_6'	Social Security S_7'	Total V'
Southern	0.4762	1.3628	0.1486	4.3263	0.4587	0.0427	0.1397	6.9550
New England-Middle Atlantic	0.3674	1.1183	0.0684	3.0864	0.1821	0.0305	0.1204	4.9735
Central	0.4414	1.2876	0.2284	4.7479	0.5320	0.0547	0.1418	7.4338
Northwestern-Midwestern	0.5525	1.7683	0.1041	4.0592	0.0963	0.0403	0.1489	6.7696
Southwestern	0.6070	1.5869	0.1742	4.4638	0.4102	0.0442	0.1447	7.4310
Rocky Mountain-Pacific	0.3551	0.8775	0.1151	4.2763	0.4428	0.0423	0.1203	6.2294

*Combinations of regions were made due to inadequacy of data for some regions alone.

National Cooperative Highway Research Project 33 summarizes the foundations of the four methods of evaluating time savings [173].

Tardiness

Tardiness, has been assumed in economic evaluations of snow and ice control to be related to losses in production and/or employee wages. In fact, no attempt to quantify tardiness due to snow storms with respect to such variables as salaried employees versus hourly or contract employees, urban (industrialized) versus rural (self employed) workers or even tempering snow storm tardiness values with normal tardiness rates.

There is some question as to the overall impact of tardiness on a company's or even a community's economy. Solicitations to government agencies, retail businesses, production companies and mining companies using time clocks revealed that normal tardiness rates are not known,

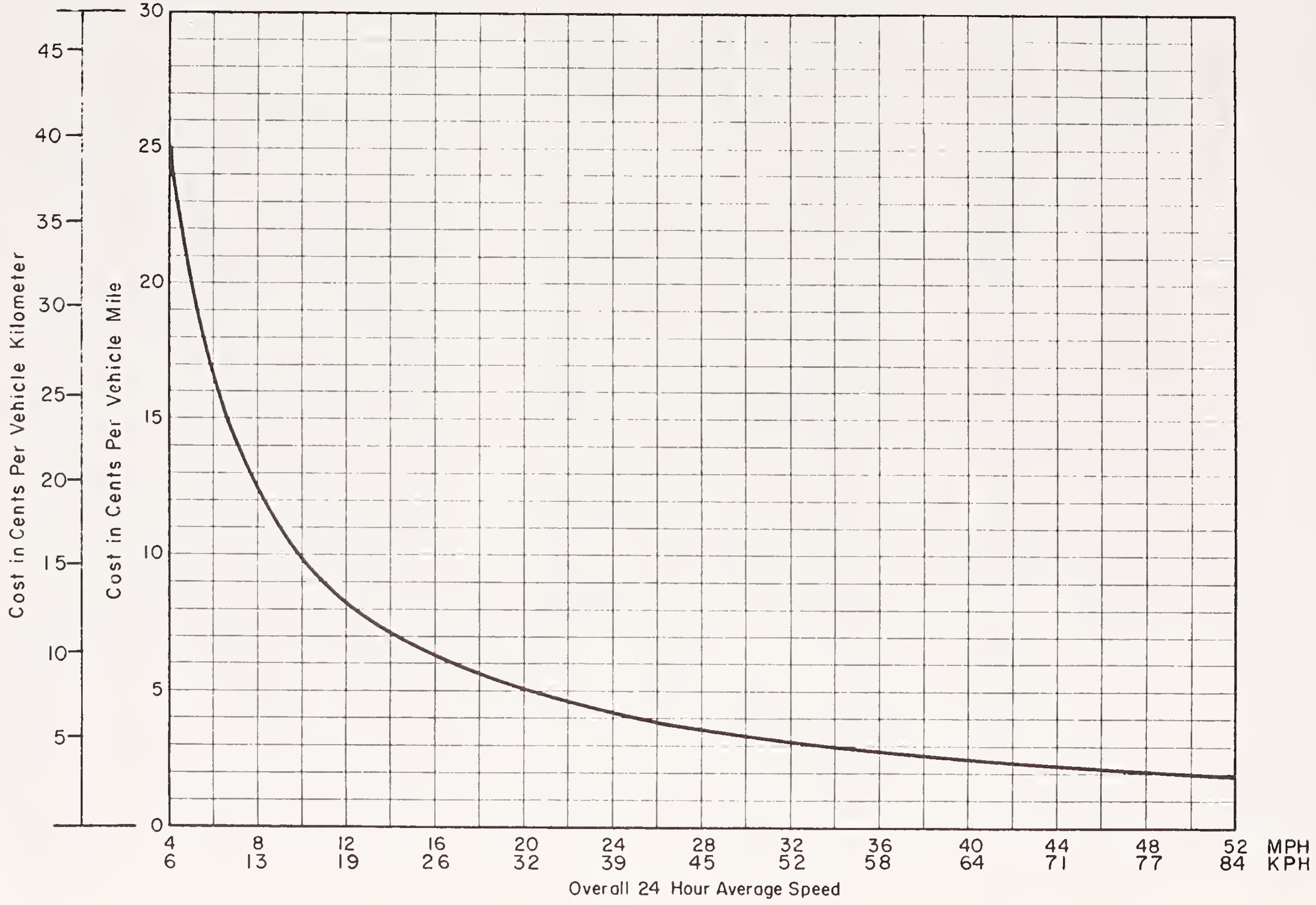


FIGURE 78: ONE DOLLAR TIME VALUE RELATED TO SPEED (142)

much less an increase due to snow or icy weather [194]. Apparently, it has not been of such magnitude to warrant special treatment by the employers contacted. It should be noted that the employers contacted are located primarily in the Utah area, with a few having offices in other states.

Economic forecasts including tardiness in the evaluation should attempt to adjust the gross approximation by the percentage of salaried versus non-salaried workers, percentage of businesses requiring an employee to remain on the job until a replacement arrives, businesses whose goal is such that small time delays do not interrupt total progress and the number of workers whose progress or lack of it does not affect the progress of other people. It is interesting to note from this study investigation [194] that tardiness and absenteeism rates during days of snowy weather were significantly lower than corresponding tardiness and absenteeism rates on a typical Monday or Friday.

When tardiness results in discernable economic losses, treatment of the magnitude of tardy time can be variable depending on income, etc. Values of time delays used by Stanford Research Institute [181] for worker trips (to the worker) may be the best estimate of tardiness values, properly prorated at this time. However, in viewing the macro-economics of the community, a loss to individual workers may not be a real cost, merely a transferred cost in the case of workers remaining on the job until replacements arrive.

Although it seems logical that tardiness and absenteeism costs are significant, their actual magnitudes are not precisely known. Further work is continuing in this area.

Comfort and Convenience

The same market considerations apply to impedance costs, the strain and discomforts of congested or nonuniform driving. Many people regard any attempt to give a dollar value to such costs on their reduction as fantastic and unworthy of attention. To this it may be replied that the Pullman Company made a very good thing for many years out of selling comfort and convenience to railway passengers. There would be no reason for people to sit down on railroad trains, let alone sleeping in a berth, if comfort had no value. Automobile and even truck manufacturers know the value of comfort and convenience to their customers and incorporate these qualities in the vehicles they design. To build the same attributes into the highways is simply following good business practice. There is no doubt that much of the popularity of turnpikes and freeways, and the willingness of people to finance them, results from the greater ease and comfort of the ride they provide [182].

It is unfortunate that guidelines suggesting comfort and convenience factors have not been developed. As for how comfort and convenience are affected by snow and ice control activities, no information is available.

Total inclement weather trip time as compared to normal trip time may be the best indicator. That is additional delay indirectly accounts for chain-up time, levels of service provided, extent of conjestion, travel speed, alternative routes and general factors contributing to inconvenienced travel.

Questionnaire approaches to ascertain the effects of snow and ice control on business, truckers, traffic and safety, yield virtually no information due to the insufficient data available in this discipline.

It is possible, that application of the "willingness to pay" method has merit in estimating a value or value range associated with snow or ice inconveniences.

In summary, traffic and safety projections used to determine economic loss from snow and ice have probably been understated in their complexity, underdeveloped relationships through research and overstated economic projections since all time losses do not necessarily represent prime dollar losses to society.

CHAPTER V

ENVIRONMENT

by: James H. Thuet

Is there an economic impact upon the environment from snow and ice control?

> "... There is no evidence that road salt is to blame for ill health of trees..." [202]
>
> "... Salts could result in significant injury to plant and animal life..." [203]
>
> "... Sodium chloride was beneficial to foliar growth..." [204]
>
> "... Deicing salts in soils are taken up by plants and cause leaf burn, premature defoliation and terminal growth dieback..." [205]
>
> "... Salt will produce varying plant responses, depending upon the soil-water content and plant sensitivity..." [206]
>
> "There is little effect on major streams due to highway salting..." [207] and [206]
>
> "... Both well and surface supplies of drinking water have been affected by increased use of salts..." [208]
>
> "... Clearly, salts used for deicing purposes do not pollute to any major extent..." [204]
>
> "... As long as salt guarantees the safety of my children, I could care less what happens to the environment..." [203]

The logical beginning to an overview of this type is to try to determine if there is an economic impact upon the environment resulting from snow and ice control. The above quotes are representative of many of the opinions found in some of the literature. Much of what is written is highly opinionated and poorly supported, however, there are several excellent studies. It is from these that an answer to the central question is sought.

Sodium chloride is the most widely used chemical for deicing purposes. As a result of this, most of the literature is concerned with the effects of sodium chloride (NaCl), either from road application or stockpile storage. There are alternatives to sodium chloride; these will be discussed as will the potential impacts to factors which make up the environment.

Additives

There are two major types of additives added to deicing salt; corrosion inhibitors and anti-caking agents.

Two basic chemicals are used as corrosion inhibitors; the chromates and the polyphosphates. Chromium-base rust inhibitors are hazardous to both wildlife and humans, [209], [211], and [202] in addition to being an extreme potential for water contamination. [212], [209], and [211]. Concentrations of .05 milligrams per liter of chromium is a sufficient amount to have water supplies rejected as unfit for domestic consumption. Other levels have been established as maximum allowable usage: stock and wildlife watering-5.00 mg/l; fish life-1.00 mg/l; other aquatic life-.05 mg/l.

Phosphates appear to be much safer than chromates, but they too have some drawbacks. Phosphates may serve as a nutrient [211] which can trigger odorous algae blooms in lakes and ponds. The effects of these blooms may in turn be toxic to fish life [206].

Another potential problem associated with the use of polyphosphates is a softening of bituminous binders [202].

Other additives used with deicing salts are anti-caking agents. The most commonly used chemicals for this purpose are ferric ferrocyanide (Prussian Blue) and sodium ferrocyanide (yellow prussiate of soda, Y.P.S.). There is some debate as to whether or not these additives are toxic to aquatic life in the concentrations used for snow and ice control.

Ferric ferrocyanide and sodium ferrocyanide are commonly used to minimize the caking of salt stockpiles. The sodium ferrocyanide in particular, is quite soluble in water, and will generate cyanide in the presence of sunlight. Tests by the State of Wisconsin showed that 15.5 mg/l of sodium can produce 3.8 mg/l cyanide after 30 minutes. Maximum levels of cyanide allowed in public water supplies range from 0.1 to 0.2 mg/l [210].

The Salt Institute maintains that ferric ferrocyanide or sodium ferrocyanide does not have the same properties as hydrogen cyanide, sodium cyanide, or potassium cyanide any more than sodium chloride has the properties of chlorine although the majority of chlorine is produced from sodium chloride. In fact, ferric ferrocyanide is the coloring ingredient in household bluing, blueprints, blue-black ink, and carpenters chalk, to name a few common items in which it is used. It has been dismissed as having a detrimental effect on fishlife.

Sodium ferrocyanide has been injected intravenously into babies and adults in kidney studies. It has also been shown in laboratory studies to be non-toxic at levels up to 5,000 parts per million (mg/l Reports also indicate that 2,000 mg/l of potassium ferrocyanide is not toxic to fish [253].

The above statements are probably correct for the unaltered chemical. The potential problems arise when the chemicals are in solution and undergo photo-decomposition.

In studies to determine the effect of sunlight on dissolved ferrocyanide, the rate of disappearance of cyanide ion and cyanide concentrations generated in solution, researchers H. W. Fiedelman and E. J. Kuhajek [253] found that after breakdown of ferrocyanide, cyanide is released into the atmosphere as hydrogen cyanide gas.

They found that sodium ferrocyanide (YPS) and ferric ferrocyanide (prussian blue) break down rapidly once in solution, particularly in shallower waters where sunlight is more intense. Atmospheric haze resulting from cloudiness as is common in winter, and normal turbidity in runoff waters and streams retard the breakdown in proportion to the reduction of sunlight penetration [253].

These researchers concluded that anti-caking additives pose no serious environmental danger.

Alternative Materials and Methods

In considering materials for snow and ice control, a variety of characteristics should be understood before the ideal one can be chosen. These characteristics include [46]:

- It must effectively melt ice, frost, and snow at low cost;
- It must not create a slippery pavement surface;
- It must not damage pavement structures;
- It must not corrode steel; and
- It must not be toxic or degrade the environment.

Primary characteristics for sensible snow and ice control methods are cost and practicality.

There are several potential chemical and nonchemical means of snow and ice control. The most promising of these are summarized in chapter three.

Salt Storage

Salt is currently used on most of the nation's roads. Since salt is so extensively used, there exists a large number of facilities used for salt storage. It is here, according to much of the literature that the chances for environmental damage are greatest. Improperly stored salt can damage surface water, ground water and plant life [215], [206], [208] and [216]. Some isolated examples resulting from improperly stored salt are examined.

> *Specific cases of water supply contamination in Massachusetts merit attention. The Town of Becket in 1951 found the water in one of its wells had drastically increased in chloride content to about 1,360 mg/1 attributable to a salt storage pile located uphill from the well ... Private and public water supplies in the Weymouth, Braintree, Randolph, Holbrook, Auburn, and Springfield areas were among those believed to be affected by highway salts, in Massachusetts. Large salt storage piles located at Routes 128 and 28 in Randolph, and located alongside the Blue Hill River, were suspected of introducing contamination into Great Pond, which serves as water supply for Braintree, Randolph, and Holbrook* [215].

Proper storage would prevent much of the potential damage from occurring. Proper storage would include one or a combination of; settling basins, paved floors, roofing and walls. Even though enclosed storage is expensive, it may represent a good investment in vulnerable areas. Proper planning can yield multi-fold benefits from storage structures during the off season resulting in a more direct cost-benefit to the using agency.

Aesthetics

What is the value of roadside aesthetics? To obtain a definite answer to this question would require answers to questions such as: how much is a rainbow or a sunset worth or the beauty of a tree and the smell of blossoming flowers?

Obviously there can be no exact figure drawn. Aesthetics are a personal characteristic common but variable for all people. To a tourist the city dump may be an eyesore; to a young boy an exciting land of treasure; and to a driver of a garbage truck the welcomed end to a hard day.

The literature on this subject is lacking. Few references are available that help in efforts directed to determine the value of aesthetics. Perhaps this is proper, because any formula attempting to derive this value would be suspect from the beginning. More research on this subject would be desirable.

No matter how difficult aesthetics are to appraise most people would agree that roadside aesthetics do have a value.

Snow and ice control can have a very definite effect on roadside aesthetics. Some of these potential effects include: erosion caused by salt kill, browned trees from salt spray, white stains on the roadside in spring after the snowbanks melt, odiferous algae growth triggered by the use of corrosion inhibitors (not commonly used) and other vegetation kills.

All of the above mentioned infer a cost. Either through loss of beauty, reduction in tourism or actual replacement or clean-up costs. For the purpose of this report, although it is recognized that aesthetics do have a value, the only costs or benefits that can be considered are those that are actually quantifiable in monetary terms. Most of the economic losses are associated with extreme or potential damage since only in isolated instances has actual damage resulting from snow and ice control deteriorated to that point.

Animal Life

From studies of salt metabolism, scientists have learned that moderate amounts of salt are absolutely essential for living organisms to survive in a precarious balance between too little, just right, and too much salt, each in accordance with its genetic limitations and special adaptations. What we need to know most of all about the effects of highway salt on the environment is what is happening to this critical balance in organisms exposed to excess salt and, in a larger sense, what is happening to the continued evolution species thus affected [207].

This sums up much of the speculation of the effects salt has on wild life. The majority of living organisms need some salt, but too much can be fatal.

Highway salting has been accused of disrupting animal life in a variety of ways. Some of these accusations include: Birds mistaking roadside salt for pebbles and dying from its ingestion [217]; animals walking through super-cooled melt water causing pain [217]; ungulate animals, attracted to the roadside to lick the salt, being hit by traffic [217]; and, the stratification of lakes causing incomplete mixing and the subsequent death of fish [248]. Another potential although indirect,impact of roadside salting could be the destruction of vegetation to such an extent that it would no longer support life. This latter potential, according to many researchers, is not as serious as may appear at first glance.

The destruction of roadside vegetation would naturally disrupt the ecosystem that may exist along the roadside. This disruption, however, would be temporary. When one habitat is disturbed, animals making up the ecosystem will seek alternative locations to live. According to several authors who have studied this subject the farthest distance from a road that highway salts will usually affect animals is fifteen meters (fifty feet). Thus, any displaced animals would not have far to go to find a suitable habitat.

Other potential harms, mentioned earlier are: Deer being run into, pheasants eating rock salt and pets walking through super-cooled water; these were considered in part by Hanes, Zelanzy, et. al. They respond that the reports attributing wildlife mortalities and injuries to deicing salts have been reputed [206]. They go on to say ... "It is thought that the only potential serious effects from using deicing salts would be the attraction of ungulate animals to highways due to 'salt craving' which could create a hazard to both motorists and animals."

Other researchers have considered the salt craving argument and found that it too may not be accurate. In Pennsylvania, approximately 25,000 deer are killed each year on the highway. Results of a study by Pennsylvania State University [201] showed that when salt is present on the highway the deer's demand for salt is at a minimum. Of course this does not mean that no roadside deaths of deer or elk have occurred due to a salt craving, but it does suggest that other causes may be present and that further refinements of presently understood knowledge need be achieved.

Perhaps one of the most serious potential problems to animal life that can be associated with snow and ice control is that under certain instances smaller lakes could become permanently stratified (irreversable damage). This process occurs when saline water (that contributed by highway salting, storage, and other sources) flows into a fresh water lake. The more dense saline water, in most instances, will move into the deeper part of the lake and may remain separate from the lower density fresh water [248]. This buildup of high density saline water can prevent a complete lake mixing in the spring [248].

Incomplete mixing of the water in spring can have a pronounced effect on the animals living in the lake ... it may result in fish kills ... or destroy the animals on which the fish feed to the extent that reduction of the fish population occurs [248].

The potential for lake stratification is real and the economic consequences could be severe. According to Bubeck, et. al. in their study of Irondequoit Bay the salt runoff has significantly changed the physical characteristics of the bay and that similar conditions might be expected elsewhere, particularly in heavily salted areas that provide natural traps. Very small and relatively deep lakes are particularly susceptible to such conditions. Indeed, one tiny lake in Michigan has been prevented from completely mixing in the spring by salt runoff. More should be known about such lakes as it is likely that salt runoff will reach more of them [248].

Either directly, or indirectly, salt has the potential to cause harm to animal life. Too much salt is a threat to all living creatures, even to plants and animals living in the oceans where salt contents average about 3.5 percent or 35 parts per thousand. Salt concentrations greater than one percent (1 gram/100 grams of water) endanger health, reproduction, and longevity in all species adapted to fresh water environments, including man [203].

Some work has been done on how much salt certain animals can withstand. Table 28, although not complete, will give an indication of the range of tolerances.

TABLE 28: SALT TOLERANCES OF CERTAIN ANIMALS

ANIMAL	CHEMICAL	TOLERANCE
Adult Rabbit [206]	--- Cl	3 grams
Adult Pheasant [206]	--- Cl	3 grams
Livestock [206]	--- Cl	
Human w/hypertension low sodium diet	Na Cl	20 mg/l
Euryhaline Fish [206]	--- Cl	20,000 mg/l
Rainbow Trout [206]	Na Cl	12,000 mg/l 20% mortality after 96 hrs. of exposure
Bluegills [206]	Na Cl	10,000 mg/l
Brooktrout [206]	--- Cl	10,000 mg/l
Crayfish [206]	--- Cl	4-5,000 mg/l
Larvae [206]	--- Cl	4-5,000 mg/l
Earthworm [206]	--- Cl	4-5,000 mg/l
Minnows [206]	Na Cl	2,500 mg/l
Minnows [206]	Ca Cl	2,775 mg/l
Daphnia [206]	Na Cl	3,680 mg/l 50% immobility 64 hrs.
Goldfish [206]	--- Cl	1,200 mg/l unaffected

Salt tolerances are not absolute; they depend on the oxygen supply in the water, temperature of the water, length of exposure, rate of salt concentration increases, and concentration and nature of other chemicals in the water [206].

Five percent of the waters in the United States which support a desirable mixed fish fauna have less than three mg/l chloride, 50 percent have less than nine mg/l chloride, and 95 percent have less than 170 mg/l chloride [206].

According to much of the literature the economic impact to animal life from snow and ice control is minimal [115]. Attention should be paid, however, to those areas where lake stratification or irreversable damage could occur.

Plant Life

The economic effects of snow and ice control on vegetation is a very broad and complicated category. Some of the questions to be considered are: How much salt will damage plant life? What is the effect of salt on the soil? How do deicing chemicals affect vegetation? What are the modes of dispersion, and how far will salts travel?

"There is little doubt that road deicers can disturb a healthy balance in soils, trees, and other vegetation comprising the roadside environment" [221]. This statement seems obviously true enough, but a problem arises when trying to define how much salt will upset this balance, and how extensive the resultant damage will be. According to the Salt Institute

> *... Salt or other deicing chemicals rarely cause permanent, large-scale harm to vegetation. Otherwise, we could look forward next spring to a barren wasteland of brown roadsides, devoid of plant life. Deicing chemicals have been used by the hundreds of thousands of tons for decades, and the greenery is still with us.*
>
> *There are isolated incidences of plant damage each winter. That is to be expected. Salt unquestionably causes occasional damage to vegetation* [246].

If this is true, as it appears to be, the economic impact, at the present, may be minimal. But will the above mentioned isolated instances of damage increase? It does seem likely if the use of salt "continues to increase" at the rate it has in the past [210].

There are a number of factors that can contribute to a decline in roadside vegetation: Some of these being rates of deicing salt application, vegetation present, drainage, precipitation, distance of plants from the road, soil composition, weed control, etc. All of these factors are interrelated, but will be discussed separately.

The Effect of Salt on Soil

In discussing the effects of salt on vegetation, it may be best to begin with a discussion of how salt affects the soil. Calcium chloride and sodium chloride are the most widely used deicing chemicals. Of these two chemicals calcium chloride seems to have the least effect. According to F. E. Hutchinson [49] ... "mixtures of calcium chloride will decrease the potential for damage to physical properties of soils as compared to application of sodium chloride singly."

Especially when application is after ice has formed, [49] he further states... "Less calcium than sodium is introduced into the environment on a molar basis regardless of melting time and temperature."

The chloride ion, present in both salts is, felt to be harmless to soils [224].

> *Deicing salts affect the physiology and growth of plants directly by altering soil solutions. Changes produced by salts in soils include: (1) increases in osmotic pressure, (2) changes in the replaceable ions, and (3) changes in the ratio of ions in soil solutions which alter the nutritional status and also causes toxic concentrations of ions to plants. Salts which contain sodium can indirectly affect plant growth by altering the soil structure, permeability, and aeration. The magnitudes of such changes depend on the amount and kind of salt, type of soil, total precipitation and plant species* [206].

Carpenter sums up much of the present thinking when he states:

> ... *Since high concentrations of sodium ions have an adverse effect on soil physical properties by causing dispersion of colloidal particles, alkali soils lack aggregation and are poorly drained structureless soils. It appears the sodium levels found at some sites in this study would suggest that road salt applications may be resulting in poorer drainage of the soils along the highway. Furthermore, the sodium and chloride levels present in these soils are rapidly approaching a point where they may be toxic to some of the desirable vegetative species growing in the area* [204].

Dispersion

The entrance of deicing salts into the roadside environment can take these routes; groundwater runoff, infiltration through the soil, and by spray from passing traffic [205], [204], [206], and [210]. Each of these modes of dispersion may present a threat to the roadside environment. Infiltration, or percolation into the soil, may sound unlikely considering the ground is usually frozen when deicing salts are applied. According to Carpenter this may not be the case. He states:

> ...*The extent to which freezing prevents infiltration depends on the type of cover, type of soil, and rate of freezing. Almost normal infiltration was found in forest soil frozen to a depth of four inches, while corn and pasture areas allowed almost no infiltration when frozen to a similar depth. Frozen, heavy textured soils allow less infiltration than light textured soils. Slow freezing is*

> *conducive to the formation of an ice with low permeability. Consequently, frozen ground conditions do not necessarily mean that salt used on highways will be drained overland to natural waterways; some may infiltrate into the frozen soil* [204].

Spray can cause damage when "supersaturated ice or snow slurries, which develop in wheel tracks on traveled roads, are slushed onto road shoulders causing high localized salt concentration" [230].

Surface runoff is potentially the least detrimental to the roadside because it is usually carried off by streams or waterways.

The distances and concentrations of road salt have been examined by several researchers, and most have arrived at similar conclusions. The concentrations of salt are highest at the soil surface next to the roadside and become both diluted and dispersed as it moves through the soil [222], [205], [204], [225], [226], [227], and [228]. There is some discrepancy as to where the largest concentrations will occur. According to Carpenter most salt will be at the 60 centimeter (2 foot) distance [204], but many of the other researchers feel there is a progressive dispersion from the roadside until a complete dilution is achieved.

The movement of salt through soil is very dependent upon existing conditions [206] and [225]. Above normal concentrations of sodium in the soil are usually found within only 9 meters (thirty feet) of the highway [225]. There have been some observations of salt in tree tissue up to 60 meters (200 feet) from the highway [226].

A build-up of salts to a critical level along the roadside may be possible under certain conditions. According to data presented by Prior and Berthouex, most salt in the soil had been leeched out by April [224]. Other researchers have reached virtually the same conclusion [204].

The Effect of Salt on Plants

"In 1957, the New Hampshire Highway Department reported 13,997 dead trees along 6,000 kilometers (3,700 miles) of highway. The cause of death of these trees was not specified. The estimated cost of removal was $1,000,000" [229], or approximately $71 and a half dollars per tree.

Statistics similar to the one above have caused highway departments, environmental groups and citizens at large to begin asking, "how?" Deicing salts are suspected, but many maintain that salt plays no major role in vegetation decline.

For example, the deputy director for operations of Ohio, where some 360,000 metric tons (400,000 tons) of deicing chemicals were used said, "We are not aware of any significant problems arising from the use of these materials ... The point I would like to make positive and unequivocal is that the Ohio Highway Department has never experienced any damaging effect to vegetation from the deicing chemicals" [222].

Others, taking a different approach to suspected salt damage, report that a seven year test on applications of sodium chloride and calcium chloride to the sites of maples, oak, hickory, black birch, ash, and white pine was carried out by the Shade Tree Laboratory of the University of Massachusetts. Results indicate that "winter road salting probably does no great harm to deciduous trees in Massachusetts"[217].

It seems certain that salt does have the potential to damage vegetation, but not so readily agreed upon is how much damage, and how it is caused.

There are two schools of thought on this question. One believes that salt is taken up through the roots, and the other side claims that any damage done results from salt spray.

Guenther Sauer is perhaps the most quoted researcher advocating that spray is the primary cause of vegetation decline. He offers the following as evidence of damage by contact with salt [230].

- Damage is restricted to the portions of the plant above the snow cover.
- Damage is primarily restricted to the highway side of the tree.
- Top growth above the spray zone is generally unaffected--damage proceeds from bottom up.
- Trees below the roadway are damaged from the top down.
- Improved growth is evident where barriers and abutments offer some protection from salt spray.
- The most succulent growth is affected--a soil build-up would affect the older growth first.
- Sensitivity varies with plant species.

Heavy damage has been found along major expressways that receive heavy and/or frequent salt applications and carry high volumes of traffic at high speeds. Less damage is evident in speed zones or on the leeward side of the highway. Little salt damage has been observed along roadways with speed zones of 50 kilometers per hour (30 miles per hour) or less. Damage may result in the deposition of salt contaminated slush beyond the curb. However, this is minimal. Damage intensity is dependent on the time of first salting, the rate and frequency of application, and the time of last application. Numerous other conditions also contribute to the extent of the damage; climatic conditions of the previous season, winter weather, wind, soil conditions, age of the plantings and dilution of the salt concentrations [230] and [231].

Sauer's theory is seemingly supported in a report written for the Maine Department of Transportation. The authors of the report state:

> *...The foregoing results clearly indicate that tissue levels of sodium and chloride were influenced by the method by which the salt was applied and the concentration of the salt solution applied. Since trees receiving foliar application were significantly higher in sodium than when salt was soil applied, these findings would tend to support Sauer's observations, even though visual injury ratings proved inconclusive in the present study* [232].

"It happens all too frequently that a healthy plant stands next to a badly injured one, or that the same plant displays healthy branches together with badly damaged ones. This demonstrates that the resistance of plants to *above soil* salt influence is a highly complex matter [231].

There is more written on salt effects from soil uptake than there is about spray and it follows that the ideas should be more varied.

The idea that salt does cause damage [206] is tempered by others who state that sodium is not the total cause of damage [205], [231], and [225]. It seems fairly well accepted by many writers that plants can accumulate salt, [206], [204], and [232] that runoff is a factor in contamination [234] and that salt enters through root uptake [205], [234], [150], [206], and [216]. According to Professor Ruge of Germany, 90 percent of the trees that die on main roads are poisoned by chloride absorption.

How salt affects plants has interested a number of researchers. Some of their ideas are: Salt reduces the soil's fertility [217] through ion exchange or by upsetting the ion balance [206]. Others have written of the "Syndrom of Sodium Accumulation" [207]. Some researchers claim that salt increases osmotic pressures [225], [230], [206] and [232] and can cause a physiological drought [216] but others do not feel the osmotic theory is entirely acceptable [206] and [205].

Other possible effects of salt are: Salt stimulates ATPase activity, [232] sodium interfers with uptake of potassium, [232] salt slows down DNA, RNA and cell division, [234] inhibits seed germination; [222] chloride or sodium in leaves may cause injury by interferring with normal stomatal closure, causing water loss [232] and [231].

All of the previously mentioned may be partial influences, but further research is needed to determine: 1) what concentrations and conditions are required to cause injury, 2) if a potential of this happening under field conditions exists, related to the salt concentrations, 3) frequency of application and 4) temperatures prevalent in snow and ice control.

Factors That Influence Salt Tolerance

There are a number of factors that can influence roadside vegetation in addition to the use of deicing salts. These include the factors that combine to make up (1) the plants total environment, (2) the climate, (3) the individual plants, and (4) a variety of external factors.

The health of a plant depends to a large extent upon its surroundings. Some of the factors that make this up include: the type of soil, [206], [238] and [232] the amount of organic material present, [222] and [232] the balance between soil air and soil moisture, [238], [225], and [227] the drainage, [206], [238], [232]) and [208] and the level of the water table [231]. Plants along the roadside have other special conditions to contend with including increased wind exposure, both natural [230], and [232] and from passing traffic [230] and [236], exhaust fumes [208], compacted soil [238] and [208] and general maintenance [150].

Climate is also a major factor in a plant's health or lack of it [206], [232], [225] and [222]. Soil temperature, snowfall and rainfall all have an influence [206], [238], [222], [231] and [232].

The individual plants and their ability to grow in a roadside environment is a very important variable [206] and [238]. Among the factors that influence a plant's ability to survive in addition to a tolerance to salt are: an ability to translocate sodium to the leaves [206], a large root/top ratio [238], the ability to withstand high osmotic pressures [238] and the age of the plant [231].

Some external influences that can affect plant life are: the amount of salt applied [227] and [232], and the presence of disease [231].

Tolerances of plants to sodium chloride have been given some attention in the literature, but practically none has been given to tolerances to other deicing agents. Table 33 in the appendix (page 227) is a compilation of the works of: The Michigan State University - Department of Horticulture [216], Field, Struzenski, et. al. [221] University of Minnesota - Department of Horticultural Science, [231] Carpenter, [204] Sauer [230] Hanes, Zelanzy, et. al., [243] Drysdale and Benner, [222] Butler, [150] Burnstein, [253] Roberts and Chittenden, [238] Prior and Berthouex, [224] and the authors of [234] and [251]. It is recommended that salt resistant plants be used alongside roadways to lessen the chance of salt induced mortality.

Water

There can be little doubt that salt has the potential to contaminate water. New Hampshire has had to replace two hundred roadside wells due to highway salts [210] and [208] and Massachusetts has had even greater problems as the following case history demonstrates ...

> *In Goshen, salt contamination has made private water supplies unusable. Motor vehicle traffic moving from the Connecticut River Valley up into the Berkshire Hills passes through this dairy and lumber town of about 500 people on Mass. Route 9.*
>
> *Goshen sits on top of a geological pocket having little or no drainage. The rock formation, which contains no natural salt, funnels drainage from the surface into the ground water. Historical records as well as tests of water elsewhere in the area show that the natural level of chloride is about five mg/l. However, water located next to the highway and serving the center of Goshen, is now contaminated by chloride levels ranging from 300 to 2,675 mg/l* [208].

The outlook for the future may broaden noticable water contamination, as is evidenced by the quantities of salt used.

Nationally the increase in use of deicing salts has been nearly exponential, with a doubling of salt applications about every five years [210].

Under severe drought conditions salt concentrations cause contamination to be more pronounced [208] and [203]. Salts derived from deicing applications disrupt natural saline concentrations in localized wells, ponds, reservoirs, streams and ground water flows [206], [208] and [245].

Salt does have the potential to contaminate water, but salts are a natural element in the environment and concentrated salt pockets do not necessarily originate as a consequence to highway related activities. All ground water contains a certain amount of natural salt [204]. Some researchers feel that domestic sewage, sulphates and other industrial wastes have a greater impact than street salting [204] and [210]. For this reason, Hanes, Zelanzy, et. al. recommend that highway agencies should not accept sole responsibility for monitoring salt contents of streams [206]. One study has demonstrated that highway salts account for only eleven percent of the chloride found in Lake Erie [204] and [207]. Carpenter states that it is doubtful that highway salt applied directly to highways will pose any threat to ground water pollution [204]. This may be true of ground water in general, however one access spot to ground waters may have detrimental effects several miles from the source problem.

A major factor in limiting the polluting effects of salt is dilution. Road salt is very soluble in water, and in solution it is in a stable state [246]. Pollution can be defined as the amount of chemical related to the amount of water present [201]. The more water present, the less amount of contamination. There are other factors to take into consideration, such as soil permeability and soil moisture [222], [246] and [206] but over all the adverse effects of salt, when found will generally be confined to an area near the source of salt [248], [218], [230], [206] and [251]. Dilution of salt in the environment is demonstrated by the following findings of Dr. Hutchinson. He has shown that shallow-dug wells within 5 meters (fifteen feet) of salted highways contain between a trace and 461 mg/l chloride. Wells less than 15 meters (50 feet) from the highway averaged 174 mg/l Streams are reported to contain 27-255 mg/l chloride, whereas ponds contained 41-110 mg/l, medium to good sized lakes (1.5-3 miles circumference) 31-101 mg/l, rivers 8-24 mg/l, and the Great Lakes 23 mg/l [248].

Although salt is applied only a few months of the year, one of its effects on water, increased chloride content is noticeable throughout the year [248], [203], [253], [215], [218], [206] and [204]. There has been some discussion about the possibility of salt accumulating from one year to the next. The studies that have been done have demonstrated both possibilities. This is probably to be expected because of the number of variables that have an influence. For example, the type of water body (lake, pond, stream, etc.) its depth, volume of flow, and soil composition all have an influence, to name only a few.

The following graphs demonstrate the variations in findings. Figure 79 illustrates a marked yearly increase in chlorides; Figure 80 shows a seasonal variation, but very little annual accumulation.

Questionnaires used by Thuet [195], asked about any environmental damage that had been experienced due to deicing chemicals. Responses were comprehensive in that federal, state and local governments were polled in addition to universities, noted authorities, special interest groups and independent consultants associated with deicing salts and/or environmental protection.

The results show a majority of the states polled have suffered some damage due to salt. Figure 81 identifies the states where damage was reported.

There are two potential sources of damage to the environment from salt; they are road application and inadequate storage. Of all the damage reported, that attributed to improper storage had the greatest economic impact upon the environment.

As can be seen by an examination of Table 29, of the forty incidents* reported nineteen were attributed to improper storage. Although this represents less than fifty percent of the number of cases

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*There are actually more than 40 incidents represented, because some states, such as Connecticut, reported that more than one well had been damaged, but neglected to state how many.

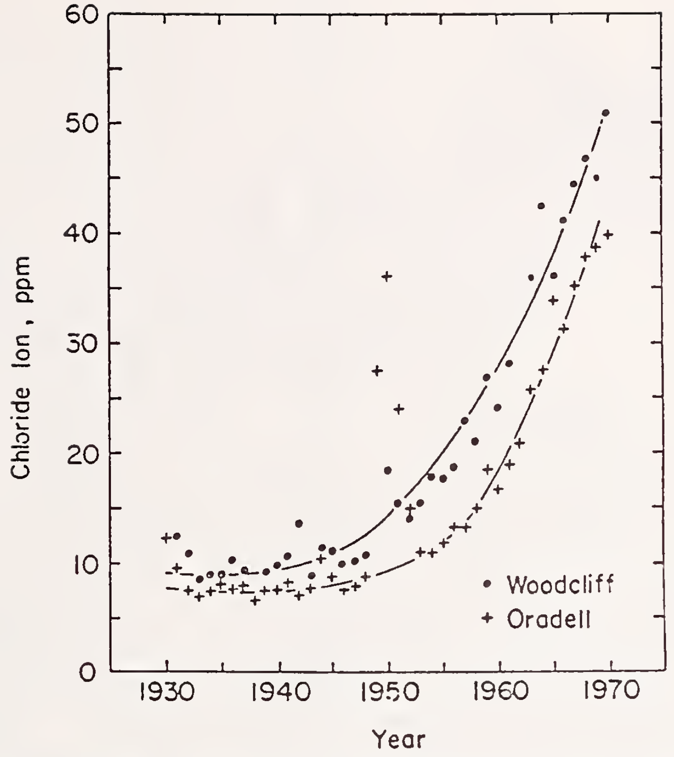

FIGURE 79: AVERAGE CHLORIDE ION CONTENT VERSUS TIME IN ORADELL RESERVOIR AND WOODCLIFF LAKE RESERVOIR

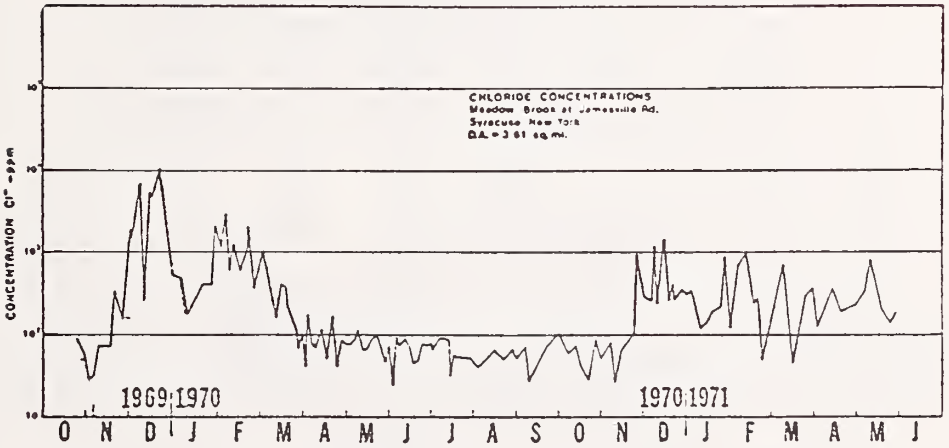

FIGURE 80: CHLORIDE CONTENT OF MEADOWBROOK AT JAMESVILLE ROAD

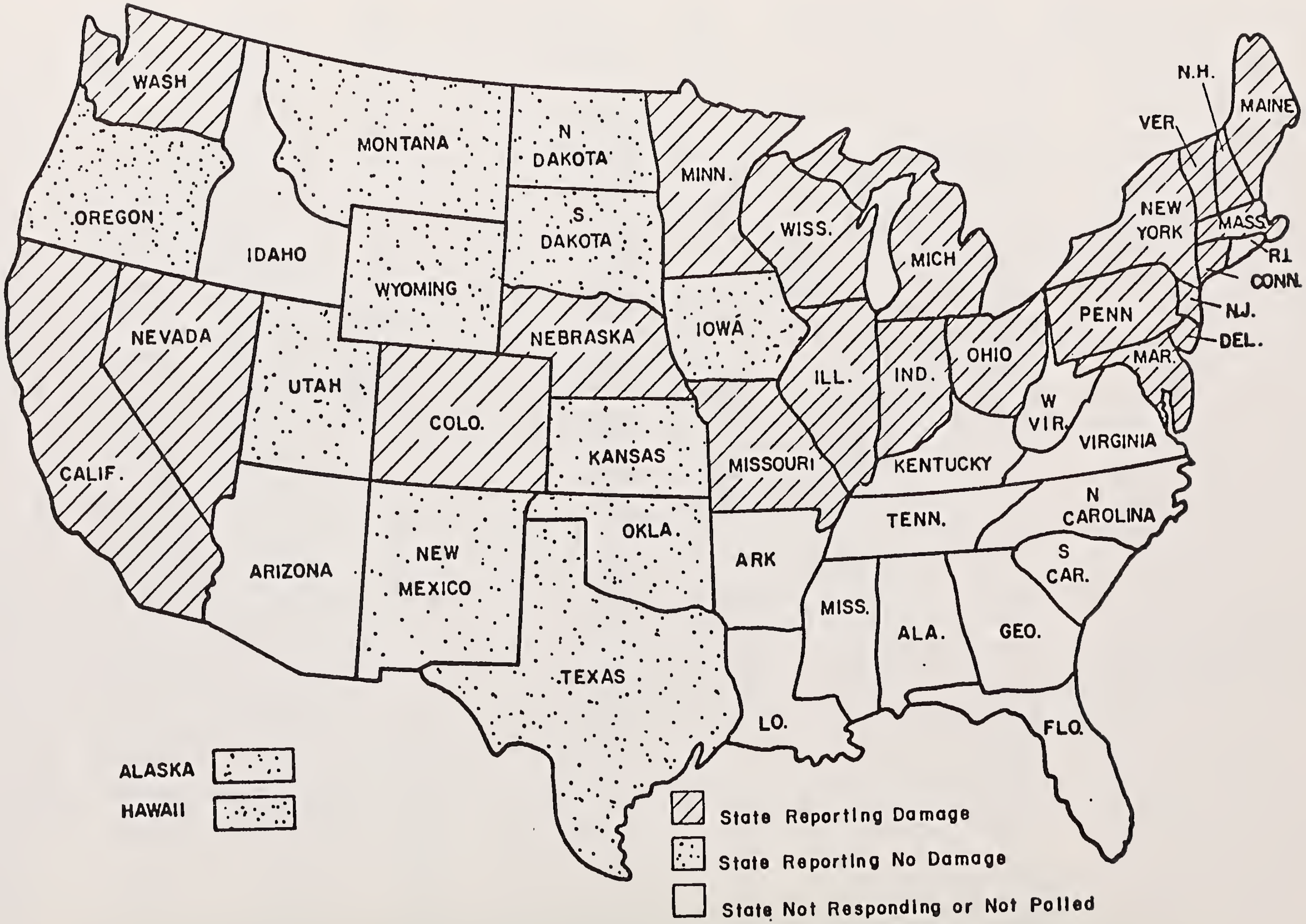

FIGURE 81: STATES REPORTING ENVIRONMENTAL DAMAGE FROM SALT

TABLE 29: STATES REPORTING ENVIRONMENTAL DAMAGE DUE TO DEICING CHEMICALS (Cont'd)

STATE	TYPE OF DAMAGE	Est. Cost of Damage	Distance of Damage		Soil Type	Buildup, or one Time Event	Amount of Salt used		COMMENTS
			Metric	Common			Metric	Common	
California	*Drainage Steam Conifers		60 m 15 m	200 ft. 50 ft.	Sand-Silt	1 Time		15-25 T/LM	Problem Solved by Inside Storage. Damage not Conclusively Linked to Salting.
Colorado	Pines		15 m	50 ft.	Varies	Prog.			1-5% of Reseeding is Attributed to Salt Damage.
Connecticut	*Well		90 m 152.4 m	300-500 ft.		Prog.			Costs were Cost of New Well & Storage.
	Maples and Pines	0	3.0 m	10 ft.	Sand	Prog.			No Drain Ditch Existed where Damage was. Six Claims a Year of Well Damage. 50% caused by the DOT. Severe Cases are caused by Storage.
	**Wells	$9000 a claim	30 m 150 m 180 m	100 ft. 500-600 ft.					
Delware	Well (1 or 2 Cases)	0	45 m	150		1 Time			
	Lawn Grass under Structure		30 m	100	Silt & Sand	1 Time	56 kg/LK	200 LB/LM per app.	
Illinois	Well		400 m	1/4 Mi. or Less		1 Yr. Prog.			Outside Storage was Eliminated.
	Crops		150 m	500 ft.					Two Incidents Reported Outside Storage Eliminated and Problem Solved.
	**Misc. Plants in Metro Areas	$50-$500 Per Mi.	3.0 m	10 ft.	Varies	1 Yr.	56-140 kg/ LK per app.	200-500 LB/ LM per app.	Costs Involved were in Rectifying Erosion Damage. No Reseeding Done.

KEY

No Asterisk = Damage from Road Applicaion
* = Damage from Storage
** = Damage from Storage and Road Application
*** = Source or Damage Undefined

TABLE 29: STATES REPORTING ENVIRONMENTAL DAMAGE DUE TO DEICING CHEMICALS (Cont'd)

STATE	TYPE OF DAMAGE	Est. Cost of Damage	Distance of Damage		Soil Type	Buildup, or one Time Event	Amount of Salt used		COMMENTS
			Metric	Common			Metric	Common	
Indiana	Shrubs & Grass Adj. to Highway		2 m	6 ft.	Sand & Clay	Each Year			Each Year 5% of Reseeding is Attributed to Salt Caused Damage.
	***Wells & Other Water	$500-50,000	400 m 800 m	1320 2640		Prog.			Will Take Between 2 to 10 Yrs for Water to Return to Original Purity.
	Salt Burns on Misc. Plants (Alleged)	0	2-1/2m	8 ft.				250 LB/LM per app.	No Specific Incidents of Known Damage.
Maryland	*Well	$86,000	30m	100 ft.		Prog.			Problem will Remain until Storage is Removed.
	Well	$300	9m	30 ft.		1 Yr.			Well was Pumped 3 Times and is Now Pure.
	Misc. Plants		3m	10 ft.	Silt, Clay Loam			300-600 LB/LM	Cost of Reseeding Due to Salt is Unknown. Gypsum is Being Applied to Leach the Chlorine Ions.
Massachusetts	***Receiving Waters					Prog.			Two Sets of Circumstances.
	White Pines, Sugar Maples		3m	10 ft.	Sandy	1 Yr.			On Usage a Gradual Buildup until Equilibrium between Amount Applied Each Year (Assumed to be Constant) and Rainfall gives a New Background Level.
	*Wells & other Water		300m 450m	1000-1500 ft.		Prog.			Salt Storage, a Buildup and then a decrease over a Period of 5 to 10 Years Depending on Soil Type and Ground Water Movement.
	Maples			*					Damage may be due to Other Sources. *In the Sections Where Trees and Shrubs are Lost, Present Design Would Not Allow Their Use.
KEY	No Asterisk = Damage from Road Applicaion * = Damage from Storage						** = Damage from Storage and Road Application *** = Source or Damage Undefined		

TABLE 29: STATES REPORTING ENVIRONMENTAL DAMAGE DUE TO DEICING CHEMICALS (Cont'd)

STATE	TYPE OF DAMAGE	Est. Cost of Damage	Distonce of Domage		Soil Type	Buildup, or one Time Event	Amount of Salt used		COMMENTS
			Metric	Common			Metric	Common	
Michigan	Aquifer	$50,000-150,000	1200m	4,000 ft w/over 250 ppm cl.		Prog.			Other Expenses include: $1,207,000 to improve Storage, $88,000 go settle Claims
	Landscape Material		8m	25 ft	Varies			13 Ton/Ln/Mi	1% or Less of Reseeding Cost is Attributed to Loss due to Salt Use.
Minnesota	Well			2 Blks.		Prog.			Salt Shed Moved & New Well Due.
	Misc. Trees	Minor	3m	10ft.	Sandy	Prog.			1% or Less of Reseeding Cost is Attributed to Salt Use.
Missouri	Aquifer Fruit Trees (1 inst.)	$100	120m	400 ft.		Prog.			$150,000 a Year Spent on Storage Bldgs. Storage Building was Constructed.
Nebraska	Minor Damage to Grasses	0	1/2m	1 1/2 ft					
Nevada	Firs	0	3m	10 ft.	Sandy			1-1/2 Ton Ln/Mi	No Positive Evidence Salt Sole Cause of Damage.
New Jersey	Wells(2) Stream	$150,000 to Date	60m 12m	Wells 200 ft. Stream-40 ft.		Prog.			One Well is Still Contaminated after 8 Yrs. The Other One is Expected to Take 20 Yrs.
New York	Well	0	60m	200 ft.	Rock Fissures	Prog.			Well Clears with Annual Use.

KEY

No Asterisk Damage from Road Application
* - Damage from Storage
** = Damage from Storage and Road Application
*** - Source or Damage Undefined

TABLE 29: STATES REPORTING ENVIRONMENTAL DAMAGE DUE TO DEICING CHEMICALS

STATE	TYPE OF DAMAGE	Est. Cost of Damage	Distance of Damage		Soil Type	Buildup, or one Time Event	Amount of Salt used		COMMENTS
			Metric	Common			Metric	Common	
Ohio	Waterway Truck Garden Misc. Plants	Minimal 0	90m 23m	300 ft. 75 ft. Wind Build-up		Prog.			Little Information Available. Storage Pile is More Carefully Handled. Runoff Damage 8-10 ft. (2-1/2-3m) from Roadway, Wind Blown Mist Damage up + 75 ft (23 m).
Pennsylvania	Wells		90m	300 ft. est.		Prog.			It is Estimated that the Contaminated Ground will Take Several Years to Clear.
Vermont	Wells & Other Waters		150m	Up to 500 ft.					Flushing Time Varies. Streams and a Few Days Shallow Ground Water, Months, Deep Ground.
Washington	Well	$20,000	30m	100 ft.		Prog.			Stockpile was Relocated.
Wisconsin	Well Minor Plant Damage in Metro. Area		60m 15m	200 ft. 50 ft.	Clay	Prog.	28-85 Kg/LK	100-300 LB/LM	Stockpile was Relocated. Yearly Cost of Reseeding due to Salt is Estimated to be Between $1,000-$5,000.

KEY

No Asterisk = Damage from Road Applicaion
* = Damage from Storage
** = Damage from Storage and Road Application
*** = Source or Damage Undefined

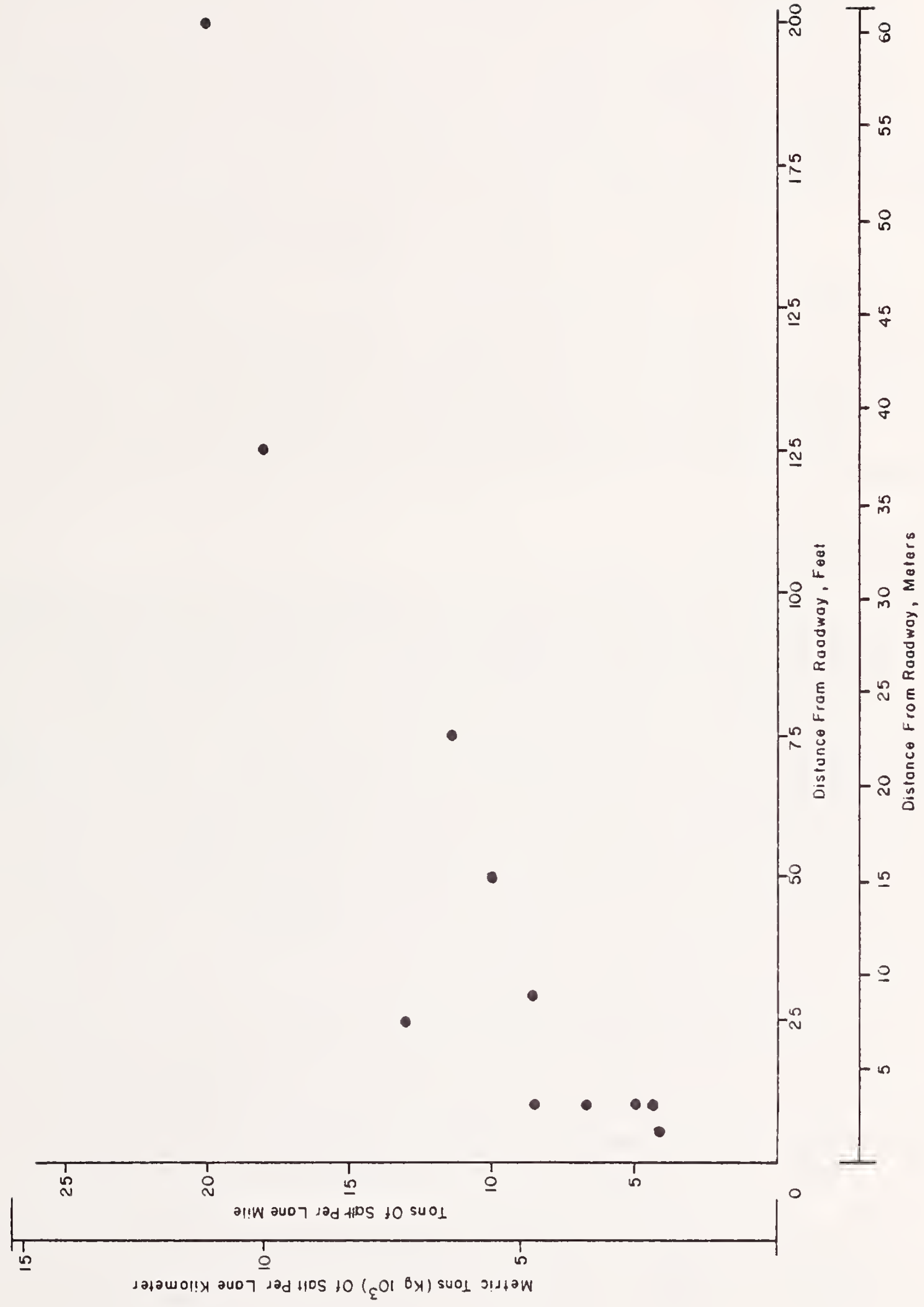

FIGURE 82: COMPARISON OF DISTANCE OF DAMAGE FROM ROADWAY AND ANNUAL TONS OF SALT PER LANE MILE APPLIED

reported, storage related costs account for well over eighty per cent of the money spent to correct salt related damage.

For example, Michigan reported that they spent between $50,000 and $150,000 for each occurrence of well damage, not including court costs, which during the past three years have totaled $88,000 and an additional expenditure of $1,207,000 to improve existing salt storage facilities. New Jersey reported that they have spent $150,000 to date on salt storage-related damage, and Maryland has spent $86,000. Other states reported they had experienced damage, and noted that the costs included replacement or flushing of wells, removal or covering of material stockpiles and court costs without itemizing dollar amounts.

The damage reported from road application is of a far smaller magnitude. The related dollar costs either took the form of the percent of the re-seeding budget spent on replacement of plants due to salt kill, or a flat dollar amount, often expressed, as Illinois did, in cost per mile ($50 to $500 to rectify erosion). Most states reported that damage from road application was minor; it occurred within 15 meters (fifty feet) of the highway and did not result in any direct costs (except possibly some cost to the roadside aesthetics).

Conclusion

The literature search and questionnaire returns [195] reveal that deicing salts can and are responsible for environmental damage, as a quick glance at Figure 81 will demonstrate. States reporting environmental damage constitute a majority of the salt-using states. This appears to be very serious, however the damage resulting from road application is isolated and usually minor. Damage induced from improper storage can be controlled by upgrading stockpile procedures. Table 29 illustrates the states reporting damage from road application. Figure 82 relates the distance from salt source to the damage and the salt application rate. Although very few states reported the actual costs involved, the few who did expressed it in proportionment of their re-seeding budget. Usually this figure was between one to five percent.

The economic impact from snow and ice control to the natural environment is a complex topic. Salt, when applied to the road, can be the primary agent of environmental degradation, but it seems to be more usual that the salt acts as a catalyst or an accelerator where a potential for damage already existed, either due to soil conditions, wind, lack of water, animal damage or other factors.

The damage caused by inadequate storage is a different type of damage, in that its consequences are far more costly and is much more easily avoided.

CHAPTER VI

ROADWAY DAMAGE

by: Joseph Leatham

The performance or life expectancy for most roadway delineation systems is a function, both directly and indirectly, of snow and ice control operations. The principle delineation systems [422] considered for examination, to determine some of the detrimental effects from snow and ice control are: pavement markings, post delineators, raised pavement markers, rumble stripes and curbs [422].

Standard striping paint, with or without reflectorizing beads, is the most commonly used pavement marking material on highways. Thermoplastics are gaining acceptance in urban areas, where there are high volumes of traffic. Specialized situations may also call for thermoplastics. The relatively high cost of thermoplastic striping (approximately fifteen times that of paint striping) has discouraged its general acceptance on rural highways [239].

Post delineators and snowpoles of various forms and shapes are used widely throughout the United States; they are effective during nighttime and during inclement weather when standard pavement markings are ineffective. However, post delineators are used only as a supplement to, and not as a replacement for, standard pavement markings.

Although a wide variety of raised pavement markers are being used, no single marker has been developed that is suitable for both daytime and nighttime use. At least two firms are developing raised pavement markers suitable for areas requiring snow removal, but adequate field evaluations are not yet available.

Raised pavement markers cost about twice as much as paint during the first year, but the costs are about equal when pro-rated over a ten year period. Life expectancy of the raised pavement markers is three to ten years on the average depending on type, traffic volumes, environmental conditions, etc.

There are no "standard" rumble strips but several variations have been used in experimental programs and in limited applications

Curbing, as such, does not provide adequate delineation unless supplemented with additional treatments, such as reflectorized paint, curb-mounted reflectors, or low-intensity lights. Due to their nearness to the traveled way, these supplemental treatments are subject to road film, with subsequent diminishing of their reflectivity. Low-intensity lights are probably least affected by environmental conditions, but are more costly than the other treatments.

Regardless of the material used, pavement markings are adversely affected by inclement weather. In snow they are completely obstructed and in wet weather their effectiveness is greatly reduced. Any substantial amount of water on the pavement will cover the beads of beaded paint stripes, and seriously impair their reflectivity. Because of this adverse environmental effect, traffic engineers have utilized post delineators and other raised markers for supplemental delineation. Many states have expressed the desire for all-weather, all-purpose delineators that could be placed on the pavement [422].

It appears that the effect of improved delineation treatments would be used most widely in those portions of the United States that are subject to snowfall. These areas were identified as lacking in proper delineation, creating locations experiencing a high number of accidents [422].

During snow conditions, pavement markings become totally ineffective because they are then completely covered or their visibility is seriously impaired. Snow removal operations using deicing salts have a deleterious effect on the life of pavement markings [255].

Pavement Paint Stripes

Mechanical abrasion from snowplowing and other equipment can cause a great deal of stripe damage. Thick stripes suffer more from snowplow damage than do thin stripes and edgelines suffer more than do centerline stripes. Raising the snowplow could reduce this type of damage but then the danger from slick pavements still remains because the snow is not completely removed.

The problem is that at present, conventional traffic markings have [254] a relatively short service life. The widespread use of studded tires adds an additional burden on these already overworked materials.

Pavement markings perform an important function in traffic control in that they are able to convey warnings and information to the driver without diverting his attention from the roadway [240]. They are used to supplement the warnings and information conveyed by other devices such as traffic signs and signals [241]. In other instances, they obtain results solely on their own merits, that cannot be obtained by the use of any other device [254]. Studded tires, when they pass over a paint stripe, fracture some of the beads and render them useless [242].

State highway officials have indicated that painted lines rarely last more than a year, and in states subjected to a winter environment, paint lines quickly fade during the winter season [258]. New Hampshire reported that they tend to use less expensive paints on open highways because even the better paints do not last through the winter [422].

Costs

The following pavement marking costs figures are based on a nationwide survey conducted by Chaiken in 1969 [239]. In this survey, he found the average cost for a continuous nine centimeter (four inch) line to be $0.022 per 30 cm (foot). The wide range of costs is probably due to different accounting practices, materials used, and painting operations. The service life can vary considerably and is greatly influenced by the climate. States experiencing heavy snow usually cannot expect more than six months of service, whereas those without snowfall indicate that paint can sometimes last more than a year.

The life of thermoplastic paint is greater when applied on bituminous surfaces than on concrete surfaces, and is also greater for non-snow states. Thermoplastics have not been used extensively on rural roads because of their higher costs [239].

Post Delineators

Post mounted delineators help outline the edge of the roadway during nighttime and heavy-snow, winter driving. These delineators usually consist of reflector units of glass, plastic, or reflective sheets, mounted on a vertical support.

It is commonly understood that post delineators are retroreflective markers placed on wood or steel posts and located just outside the right or left shoulder edge. The delineators receive their reflectivity by returning an incoming light ray in an opposite and nearly parallel direction. The delineators are normally placed from one meter to a meter and a half (three to four feet) above the pavement, making them visible at night and during inclement weather when pavement markings become ineffective [422].

The actual delineator, if kept clean, normally has a long life. But frequently delineator reflectors and posts are prematurely destroyed when vehicles and snow removal equipment encroach on the shoulder of the road. New Hampshire reported that on the average 50 percent of their delineators needed repair or replacement during each winter season. During the especially severe winter of 1968-69, 75 percent of New Hampshire post mounted delineators received some sort of damage.

The installed cost for post-mounted retroreflective delineators ranges from a low of $3.00 to a high of more than $5.00 each. The range is attributed to the different types of posts and reflectors available. The service life of a post delineator is not easily determined; it is not a direct function of time and traffic wear as in the case of paint. Damages usually arise from snowplowing operations, shoulder encroachment of vehicles, and vandalism [422]. States with heavy snow have experienced a fifty percent or more replacement factor each year. The figures for five years are based on a replacement factor of twenty percent and a spacing of 61 meters (200 feet) which is normal for tangent sections [422].

Raised Pavement Markers (RPM)

The principle advantage of raised pavement markers is that they provide both near and far delineation, limited somewhat by the vertical profile of the road. As compared with painted lines for near delineation, raised markers provide increased visibility, particularly on rainy nights. But, in areas where snowplows operate, the standard types are often destroyed [422].

Markers are still in the developmental stage, but most of the snow-free states have installed at least a few test sections; California has installed several million raised markers [422].

The common markers cannot be used where snowplows operate and studded tires are used. Although a few commercial firms are working on this problem, a totally satisfactory snowplowable marker (cost and performance) is not yet available [422].

Most markers are attached by epoxy adhesive, but some are bolted; the snowplowable type are generally set into the pavement. They can be attached to asphaltic concrete pavements or portland cement concretes. The pavement must be clean and usually is sandblasted to remove dirt, oil, and grease before attaching. Epoxy adhesives are very strong and generally the removal of a marker will damage the concrete (the bond is stronger than the concrete). Special equipment has been designed to facilitate installation of markers [422].

As indicated earlier, snow removal presents special problems because the snowplow's blades tear the markers loose. Several groups are working to solve this problem. Stanford Research Institute has developed a raised pavement marker with a low profile that they believe should be less subject to snowplow damage and also not require removal for resurfacing [257].

Spring-loaded and rubber-edge plow blades are being tried, but chemical snow removal seems to be the better solution in areas of light snowfall. Washington has also experimented with snowplows with a polyurethane edge [135].

Special markers are being designed to withstand the snowplow blade. Stimsonite's marker (a reflex unit in a steel casing) is being tested in Pennsylvania and New Jersey. A few of the Traffic Standard, Inc., markers (a reflective unit placed in a plastic/rubber housing) have been installed in New Jersey to test their durability [422].

Another approach to the snowplow problem is to specify the use of rubber-edged snowplow blades. This has met with resistance from maintenance personnel, however, and there is considerable doubt whether this will be a satisfactory solution (See Chapter 3) [135].

Studded tires damage all markers to some degree. Pitting is greater on ceramic markers; scratching is greater on reflective markers; a skidding studded tire gouges all markers [257].

Formed in-place, wet reflective markers with 0.25 inch diameter beads embedded in a pigmented epoxy base are severely damaged by steel snowplow blades, studded tires, and chains.

When widespread application is considered, raised pavement markers on the center line provide the most merit per dollar of investments. However, if the budget is limited, it may be more desirable to provide painted center lines over more curves as the merit/cost ratio is nearly the same and the investment per site is much less. On the other hand, if painted center lines are already provided and replacement by raised pavement markers is not feasible (perhaps snowplows operate in some parts of the state), the addition of post delineators to the outsides of the curves will provide a very strong treatment with a high merit/cost ratio [422].

A wide variety of raised pavement markers is available; unit costs range from a low of $0.25 each for non-reflective markers to $1.25 or more for reflective markers. Snowplowable markers cost from $3.00 to $5.00+ each. The life of the markers for non-snow states appears to be between three and five years, with a loss replacement factor of about ten percent per year [422].

Rumble Strips

Rumble strips are intended to alert the driver's visual, auditory, and tactile senses simultaneously. Research has shown that brake reaction time is faster with an audible stimulus than with a visual stimulus alone. Further reductions in reaction time have been noted when the stimulus effects more than one sensory.

Most installations of rumble strips have been experimental to date. When placed longitudinally, they are used to both delineate and define the edges of the roadway. In addition to providing a rumble effect if the driver should stray from the roadway, they are more visible than regular traffic paint during inclement weather [422].

On very sharp curves where an accident problem exists, use of transverse rumble patches is recommended. Patches consisting of a series of transverse spray thermoplastic strips, thirteen cm (six inches) wide with thirteen cm (six inch) spacings, are effective and not objectionable. These lines hold up well under snowplowing. A set of three of the patches on each approach is suggested [422].

It was found that the rumble strips required considerable maintenance and periodic patching when cationic asphalt emulsion was used as the bonding agent. Chemicals had to be used to remove snow and ice during the winter because snowplow blades damaged the strips. It is theorized that the use of epoxy resins would bring the amount of maintenance down to a reasonable level [422].

Rumble strips are applied in several ways. The most common treatment consists of stone chips bound by some type of adhesive mixture, or simply a one cm (1/2 inch) layer of bituminous concrete. The average cost of this type of application is about $2.00 per .836 square meter (square yard). A service life of five years can be expected in most cases, with little or no maintenance. Hence, the total cost for five years is the same as the initial installation cost. Another type of rumble strip is scored concrete. Although it has been placed transversely across the pavement, it is generally used for median sections running longitudinally. This application has an average cost of about $4.00 per 30 cm (foot) for a 1.2 meter (four-foot) wide stripe. Again, little maintenance is required during a long service life; sweeping or some other type of cleaning will be required where sand or cinders are used for anti-skid control on icy pavements or when other loose material is present on the roadway [422].

CHAPTER VII

VEHICLE CORROSION [394]

by: Michael C. Belangie

Vehicle corrosion is a worldwide phenomenon influenced by geography, atmospheric conditions, owner care, automotive manufacturing practice, deicing methods, and governmental policies. Corrosiveness of the environment varies from marginal in dry, clean air environments to extremely corrosive in heavily air polluted, hot, maritime regions.

The degree of corrosiveness to which a vehicle will be subjected is determined primarily by the location in which the vehicle is operated. Climatic conditions; proximity to bodies of water, and, to a substantial degree, industrial pollution and deicing salt applications are inherent characteristics of a given geographic area. Although each of the characteristics cited contributes to corrosion, it is only when they are viewed as a group that the level of corrosiveness of the area can be compared.

Governmental policy, as it affects air pollution and deicing salt use, is the major manipulatable element available to alter the corrosiveness of a given environment. Fromme's work (185) in Canada, described a fourfold increase in corrosion rate when comparing atmospheric corrosion between a rural farming area and a heavily industrialized district. Both the American Public Works Association (186) and Fromme (185) described a twofold increase in corrosion rate as a result of deicing salt usage.

The atmosphere is both the principle moderator and the source of the corrosion process. It supplies two of the three constituents - oxygen, water and metal - which are required for corrosion to take place. In addition, climatic conditions serve to either accelerate or decelerate the corrosive process. For instance, corrosion rate approximately doubles for each ten degree Celsius (18 degrees Fahrenheit) rise in temperature above zero degrees C (32 degrees F). If the relative humidity is below fifty percent, the corrosion rate is negligible. Between 50 percent and 70 percent relative humidity there is a critical humidity level, the exact level differs from metal to metal, but once this level is passed corrosion rate increases rapidly.

Dissolved oxygen content in solutions is primarly a function of temperature and solution agitation. In the former instance oxygen level drops with increasing temperature, tending to slow the reaction. Agitating the solution encourages the dissolution of oxygen which tends to maintain or accelerate the reaction rate.

Air pollutants in the form of oxides of sulphur, carbon and nitrogen as well as hydrocarbons and ozone comprise the principle molecules acting as accelerators or catalysts in the corrosion process.

Airborne chloride compounds are typical of coastal regions where salt crystals are one of the principal sources of nuclei around which raindrops form. This effect may be a significant factor contributing to the high rate of corrosion in these areas.

Corrosion is neutralized when the solution is frozen. If the solution is prevented from freezing by a lowering of the freezing point then the additional corrosion is a function of the combination of elements lowering the eutectic point. However, as indicated earlier, at low temperatures the process proceeds more slowly.

The chloride ion attacks metal in three ways. Its most destructive aspect is the ions mobility - its ability to penetrate existing oxide deposits thus continuing the corrosive process. The other two aspects of the chloride ion are electrolytic activity and the lowering of the eutectic point (freezing point of the solution). These traits it shares with other ions such as SO's, NO's, CO's as well as the whole spectrum of soluble salts.

Highway maintenance practice contributes to the vehicle corrosion problem in two ways: 1. deicing salts (sodium chloride and calcium chloride) are by far the major contributors; 2. dust control agents, particularly calcium chloride, are used on a limited number of unpaved rural roads, and are a secondary contributor.

The automotive manufacturer determines, via his design, materials, and manufacturing techniques, the degree to which his product can resist the corrosive factors in the environment. His ability to do this is directly related to the availability of corrosion resisting materials and processes that are economically available to him; and that can be incorporated economically into his capitalization and plant renovation programs as affected by his overriding criteria - to maintain his competitive stance and not overprice his product.

The owner who drives his vehicle in a relatively air polluted environment; uses highways on which deicing salts are applied; and then parks his car in a heated garage, is subjecting his vehicle to an intensely corrosive environment. As the temperature and the relative humidity of the garage rise and the electrolytes are freed from their frozen state, the corrosive process moderated by the temperature and relative humidity of the garage, accelerates rapidly [237].

Chemical inhibitors, added to deicing salts, have been extensively evaluated. The consensus of opinion is that under field conditions they are ineffective. The tehcnical Practices Committee of the National Association of Corrosion Engineers stated in Technical Publication 3N175 (187) "there appears to be no easy and effective way to inhibit the corrosion of autobody steel by adding chemicals to deicing salts or to the streets directly."

"Increased depreciation cost, resulting from corrosion damage, and in particular, damage resulting from deicing salts, are extremenly difficult to assess for the average automobile." (187) Particularly since the relative extent of the corrosion damage caused from air pollutants, variations in manufacture, humid environments, deicing chemicals, etc., are difficult to differentiate. But this has not prevented the use of high projected corrosion costs, to the vehicle owner, from being bandied about in professional meetings and the floors of various legislatures. Multiple references in professional journals, legislative reports and media sources refer to a $100.00 per year cost in vehicle damage due to corrosion [233], [235].

> *It has been widely quoted that corrosion damage devalues the average automobile by about $100 annually. The widespread use of this number is regrettable because it was not derived on the basis of an economic study. The "$100 annual loss" was simply estimated and should not have been construed in anyway as being quantitative or even semi-quantitative* [*187*].

Based on the year this number was introduced, the "present worth" for 1976 would show an average of $185.09* per year for vehicle corrosion. The application of this kind of damage cost to vehicles to be manufactured in the late 70's and early 80's is extremely questionable when considering a statement by a principal metal coating manufacturer that "the additional cost of coating all the uncoated steel, approximately 230 kilograms (500 pounds,) with a patented sacrificial zinc plating would cost about $35.00 per vehicle." (188) This coating has performed better than either galvanized steel or zinc rich primers in salt fog-chamber tests; and is presently being incorporated into both GMC and Ford products. It is expected to yield a minimum corrosion-free life expectancy of five years. (189) The technical basis of coil-coating is described in reference (220).

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*Accumulated by eight percent depreciation over eight years.

CHAPTER VIII

STRUCTURAL DETERIORATION

by: Michael C. Belangie

Introduction

Processes affecting reinforced concrete structures are complex and are characterized by interaction rather than isolation. External environmental factors and internal stresses interact within structures, both at the boundary layers and throughout the matrix of the structure. Some of these interactions are positive and contribute to the strength and/or life expectancy of the structure. Others are negative, causing deterioration and accelerated aging.

Ample information is available in the literature as to known and hypothesized non-deicing salt sources of structural deterioration (References to this literature will generally follow the section headings). The bulk of this chapter will be devoted to winter or winter maintenance related damage and its prevention.

Legalized use of studded tires [259], [260], [261] and [262] and winter maintenance activities, specifically the use of deicing chlorides, [263], [264], [265], [266], [267], [268], [269], and [270] are continuing to have a significant impact on structural deterioration. Stud damage, either to structures or roadways, is limited to rutting of the surface. However, in the case of structures a reduction in surface thickness can reduce the time-to-corrosion of deck reinforcing steel. Salt, while heavily impacting the decks, is also affecting critical portions of the supporting elements [271], [272], [273], [274], [275], and [276] , [391].

State policy determines studded tire use, and indirectly, deicing salt usage; the latter via maintenance policies. The legal requirement to implement bare roads policy, in combination with finite maintenance budgets and the apparent cost effectiveness of snow removal by salt, will continue to bind highway maintenance agencies to deicing chlorides, until a viable alternate(s) (see Chapter 3) is found.

In the course of this chapter, its appendices and references, statements may be made that seem to imply an exclusive relationship between salt (chloride) and structural deterioration; under no circumstances should structural deterioration, specifically or generally, be considered an exclusive result or product of salting. Chlorides are necessary to initiate this process. The degree to which salting contributes is a function of several additional factors.

Estimates of structural deterioration costs, due to deicing chlorides alone, vary from $70 million [276] to $500 million [277] annually; and in the case of the minimum estimate, are predicted to eventually rise to $200 million annually [276]. If costs of this magnitude can legitimately be assessed against deicing chlorides then the cost effectiveness of salting, and indirectly, the validity of bare roads policies, may be questionable. In a similar manner, if studded tires are to be allowed, then the convenience provided to the driver by studs must be equated against the cost of repair to the abraded surface, as well as to any structural deterioration attributable to the broaching of waterproof surfaces.*

In constructing a base on which to develop estimates of structural damage costs, due to either deicing chlorides or any other environmental chloride source (calcium chloride used in the dust control [278]); a complete recognition and allowance for the contribution of other deterioration mechanisms and their effects must be made [278] and [187].

Water

Of all the factors affecting structural deterioration, water is the most pervasive [279], [280], and [187]. Absolutely essential to concrete construction and curing, water becomes when in excess, both during construction and for the life of the structure, the principal aggressor on reinforced concrete, particularly in areas subjected to freeze-thaw conditions [281]. Without moisture in sufficient quantity, neither corrosion of steel nor deterioration due to freeze-thaw are possible. Improper control of water during mixing, construction or curing results in a multitude of deficiencies [280] and [282] which weaken the structures capacity to resist detrimental environmental factors. The inability of structural systems to: remove water from the surface, stop its permeation into the matrix, and prevent its contact with susceptible surfaces will result in early deterioration of the structure [270] and [283].

Almost all deterioration mechanisms are controlled, moderated [284] or assisted by water [278]. Any factor which reduces a structure's ability to: prevent water from entering the concrete matrix, shed water from the structures exposed surfaces, and prevent its contact with unexposed sheltered surface, is detrimental to the structure [285] and [286].

Chlorides

Certain chloride ion effects are specific to concrete. The

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*Other negative effects of studs have been evaluated in an FHWA policy statement [260].

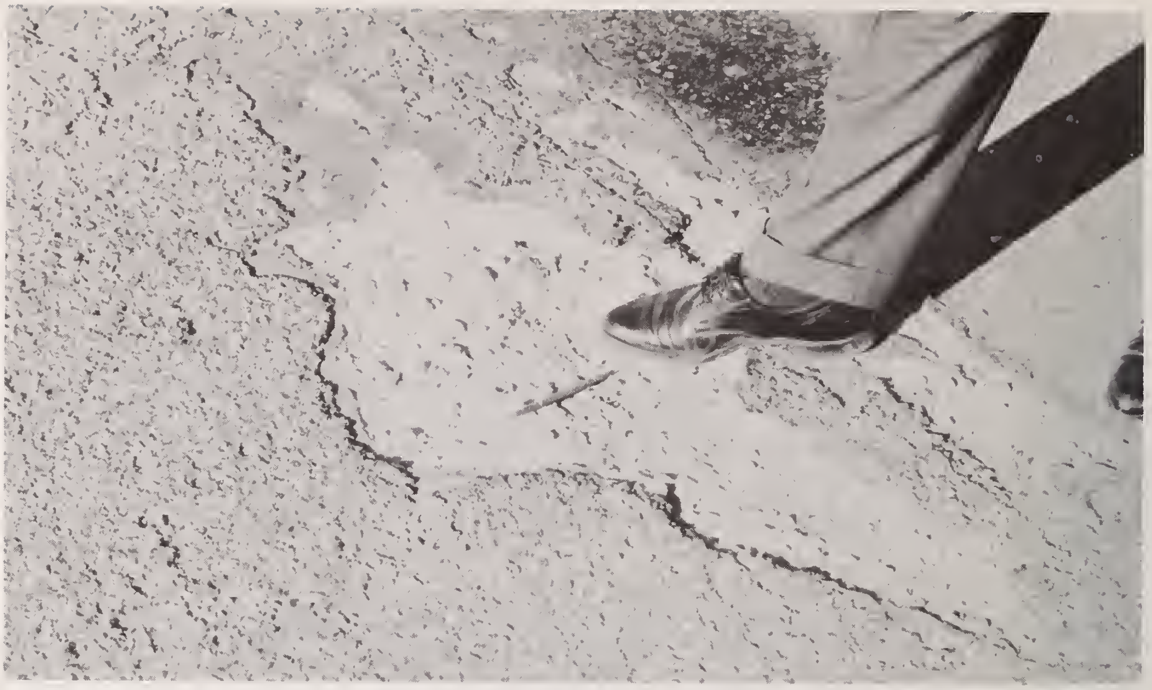

FIGURE 83: SCALING AND DECK DETERIORATION (Courtesy South Dakota Department Of Transportation)

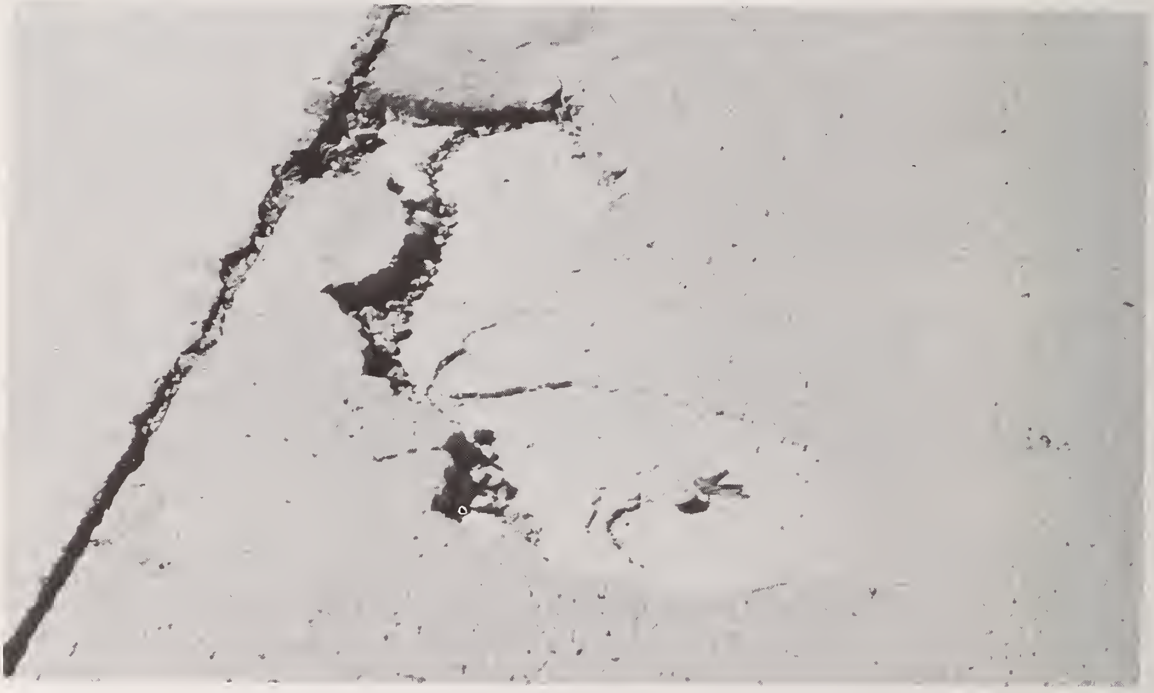

FIGURE 84: SPALLING (Courtesy South Dakota Department Of Transportation)

discernable aspects of these effects are described by the terms scaling, cracking, delamination and spalling. These terms describe physical damage and are nonspecific to damage resulting from salting. In a typical, unprotected deck the following sequence of deterioration might be expected to occur.

Chlorides - Scaling [287], [288], [289], [290], [291], [292], [293], [294], and [295]

As concentrations of salt in the surface wearing layer begin to build, the freezing point of the surface drops. The result is an intermittant surface layer which fails to freeze or freezes after the layer below it. The stresses set up in the boundary planes by the differential freezing of the chloride contaminated upper layer, are sufficient to initiate and propagate cracking. The process is accelerated through the infiltration of water into the boundary zone via vertical cracks, capillarities and other discontinuities. The net result of the described processes is binder deterioration, internal cracks, small popouts and a generalized scabbing of the affected wearing surface. This type of surface deterioration is referred to as scaling. Scaling continues at an elevated rate as long as the surface structure, consisting primarily of fines, is intact. However, as the larger subsurface aggregate is exposed, the concrete matrix deterioration process slows and continues at a reduced rate.

At some point in the time frame, during which scaling is active, a second process, delamination, resulting directly from rebar corrosion begins. Depending on which source is referred to [265] and [296] the initiation of the corrosion process leading to delamination can begin at chloride ion concentrations of 1.18 [269] kilograms and between 0.59 [265] of salt per cubic meter (1 to 2 lbs./cu.yd) of concrete.

Chlorides - Reinforcing Steel Corrosion [287], [297], [298], and [299]

Reinforcing steel completely embedded in an intact concrete matrix can be encased in a highly alkaline (pH + 13.5) environment [266]. Steel immersed in a solution of this alkalinity corrodes at a relatively slow rate [300]. Chloride salts, regardless of source impact the alkaline-moderated solution of the steel-concrete interface by supplying free-chloride ions which act to partially neutralize the solution [278]. (Free-chloride ions in solution are highly mobile and readily permeate typical structural concretes.) This partial neutralization reaction approximates a threshold reaction in that the electrochemical reaction curve rises rapidly with a slight decrease in pH below the critical pH of the material. This decrease in pH can be initiated by a nominal increase in free-chloride ion over the critical concentration of free-chloride required for depacification. The actual concentration of chloride required varies with the composition of the matrix.

In the typical rebar corrosion reaction one segment of the rebar acts as an anode and another segment acting as the cathode. Both anode and cathode segments must have sufficient free-chloride ion concentrations to be in the depacified state [266].* Chemical modifiers affecting rebar corrosion in concrete have not been extensively explored, but based on various reports [301] and [187] it would appear that both buffering effects and loosely-bound metallic ions associated with either the aggregate or the mortar constituents could act to increase the concentration of free-chloride ions necessary to produce depacification. Whether or not increasing free-chloride ion concentrations will accelerate the corrosion reaction after the initial sharp rise accompanying depacification has not yet been quantified.

Chlorides - Delamination [287] and [297]

Once the corrosion mechanism is active and pressure generated by the corrosion products build, the concrete, unable to withstand the pressures generated, (in excess of 316 kg/cm^2 [4500 psi]) cracks. (Iron oxide corrosion products produce a volume approximately 2.2 times greater than original steel) [302]. Normally a vertical crack will form above the rebar, while a horizontal crack is initiated in the plane of the rebar. Freeze-thaw in conjunction with surface water entering the crack system plus additional stress from fatigue mechanisms and traffic loading impacts causes rapid expansion of the fracture planes; intersection of the resultant crack systems initiates spalling.

Chlorides - Spalling [287], [269], [297], [303], [304], and [291]

The spall then is the next major phase of deterioration [305] and [306]. "Spalling usually occurs near or over reinforcing steel with portions of concrete removed, revealing roughly horizontal or inclined fractures. Concrete is often gone from areas not directly over bars but associated with them. A vertical crack may be present over the bars" [296]. Once delamination has occurred both live loadings and thermal stresses act to develop cracks between the delamination and the surface. These intersection crack planes eventually define the limits of a given spall and act to sever the spalled material from the deck proper.

Design Related Mechanisms [307], [308], [309], [310], [311], [312], [390], [393], [399], [403], [408], [410], [412], [413], [414], [416], [419], [420], [421], and [423].

Presently, a design's principal concern with the prevention of corrosion is choosing among the various anti-corrosion techniques available. Since the performance of almost all of the techniques are to some degree ambiguous, the decision is a risk choice.

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*Depacify and depacification are terms used to describe steel actively undergoing corrosion as a result of a reduction in pH, typically caused by chloride ions at the steel-concrete interface.

To reduce this risk element the design and specification developed should emphasize quality construction. The reasons for this are discussed in the following sections. But in summary they can be expressed as follows: If the prevention system fails then the design and construction of the structure proper determines the structures ability to resist corrosion related deterioration.

Depth of Cover

Spalling is attributed to corrosion of the top mat of reinforcing steel due to the penetration of water and deicing salts. The closer the steel is to the surface, the more vulnerable it is to corrosive attack. If the current studies to evaluate bridge deck protection systems should prove waterproofing membranes to be the most practical and effective means of protection, depth of cover over the steel will no longer be an important durability factor [313]. However, the results of these long-range studies will not be known for some time.

Present literature contains a large number of selections discussing the advantages of adequate depth of cover over reinforcing steel. Most sources recommend at least five centimeters (2 in.) [300], [314], [315], [316], [313], and [304]. However, recent FHWA studies have shown that chloride ions will eventually penetrate five centimeters (2 in.) of even high quality low water cement ratio (0.4) content concrete [305].

Cracking [281], [297], and [317]

For a period during the 1950's and 60's structural design trended towards minimal cross-section designs having considerably less resistance to flexure than either earlier compressive designs or later enlarged cross-section designs. During the same period a shift in emphasis from simple span design approaches to continuous span concepts also occurred. In the former instance vibration and excessive flexure have resulted in increased crack formation. In the latter case continuous spans have produced negative moments with increased surface cracks being noted.

In general cracking causes localized corrosion and until depacification of the steel takes place, as a result of chloride penetration of the deck matrix, the corrosion is generally limited to the immediate crack area.

A number of references are made to vibration [318], [291] and [296] and the effects of negative moment [302] on crack propagation. It is only when the resultant cracks become coupled with zones of weakness or fracture planes, resulting from inappropriate design, specifications or construction procedures that serious surface deterioration, or spalling begins.

Drainage

Removal of water, salt contaminated or not, in the shortest reasonable distance and as rapidly as is feasible is an important design consideration. A Kentucky report [282] suggested, that "From the design standpoint, there appears to be definite advantages in having drains closely spaced. Decks should be placed on a grade and crowned whenever possible."

Joint Design [271], [274], [272], [319], [273], [270], [272], and [283]

Joint design has a critical impact on both deck and superstructure protection. Failure of the joint waterproofing system allows water to reach the substructure resulting in its eventual deterioration. This substructure deterioration can weaken the deck support system and cause damage to the deck.

Construction [281], [320], [386], [321], [322], [323], [312], [395], [400], and [417].

It is generally accepted that standard quality concrete construction cannot successfully resist chloride penetration. The extent of this ineffectiveness is indicated in the following excerpt from TRB publication #500 [264].

> *The time-to-corrosion tests on (typical)* bridge deck concrete yielded the most striking (and disturbing) finding of the study. The summary given in Table 30 shows that the time-to-corrosion for the typical uncracked bridge deck concrete with 1-in. (25.4-mm) reinforcing steel cover was only 1 week (7 applications of a 3 percent NaCl solution) in many instances. The test procedure corresponds to a daily NaCl application rate of only 0.2 lb. (0.09 kg) NaCl per 20 ft.*^{2} *(1.85 m*^{2}*) of concrete surface. Therefore, the total salt applied prior to initiation of corrosion was 1.4 lb. (0.64 kg) over the entire 20-ft*^{2} *(1.85-m*^{2}*) slab. The maximum time to corrosion for this concrete (in the instances where electrical potentials permitted determination of a valid time to corrosion) was four weeks (28 de-icer applications). The total quantity of NaCl applied to this instance was less than 0.3 lb/ft*^{2} *(1.5 kg/m*^{2}*) of concrete surface.*
>
> *This finding shows that uncracked quality concretes*, similar to those used in field construction, provide little protection against reinforcing steel corrosion when the*

**water/cement: 0.5; cement content: 658 lb/cu yd; slump 3 + 0.5 in.; air content: 5-7%; vibrated rodded unit wt: 99 ± 1%.*

> *reinforcing steel is placed at a 1-in. (25.4-mm) depth. It substantiates the necessity of modifying present bridge deck concrete mix designs and the need to use alternated means of preventing de-icer intrusion. This finding should also lay*

TABLE 30: TIME-TO-CORROSION OF SLABS EXHIBITING POTENTIALS CONSISTENTLY GREATER THAN 0.35 V CSE [264]

Slab Number[a]	Special Treatment	Corrosion (week)[b]
72-7		1
126-126		1
127-127		1
116-118	50.8-mm(2-in.) reinforcing steel spacing	2
117-119	50.8-mm(2-in.) reinforcing steel spacing	1
78-19	Burlap cure	2
62-22	Poly-sheet cure for 3 days	2
51-24	Poly-sheet cure for 7 days	3
50-69	Permanent metal forms	2
63-70	Permanent metal forms	2
32-70	No rain (cover over slab)	2
106-74	No rain (cover over slab)	1
34-77	Chromate inhibitor	4
71-78	Chromate inhibitor	2
55-89	Monthly NaOH wash	4

[a] Concrete for all slabs listed had a water-cement ratio of 0.5 content of 390 kg/m^3 (658 lb/yd^2), and a cover over the reinforcing steel of 25.4 mm (1 inch).

[b] One week is equivalent to 7 daily applications of a 3 percent sodium chloride solution ponded to a 1.6-mm (1/16-inch) depth.

> *to rest the misconception that cracks are necessary for deicer-born chlorides to get into the concrete.*

The preceding laboratory findings have been confirmed in a number of field studies. In the same publication [264] a field study involving three decks substantiated the previous findings and indicated the positive effects of increasing the depth of cover above the reinforcing steel.

Figure 85 illustrates more clearly the relationship between depth of the reinforcing steel and the amount of deterioration of the bridge deck. Time correlates directly with deterioration and the relative percentage of deeper steel increased but not nearly as rapidly as with shallower steel. The sixteen year curve shown in Figure 85 represents the deck surface area actually removed for repair purposes when a five centimeter (2-in.) bonded portland cement concrete overlay was placed on the deck [300]. This figure shows the importance of placing the steel as deep as possible. Where the average steel depth was five centimeters (2-in.0 on this deck, only eight percent of the area was associated with the deterioration after sixteen years. Nearly all of that was related to expansive chert aggregate with the remainder being ascribed to reduced, 3.8 centimeters (1-1/2 in.), cover.

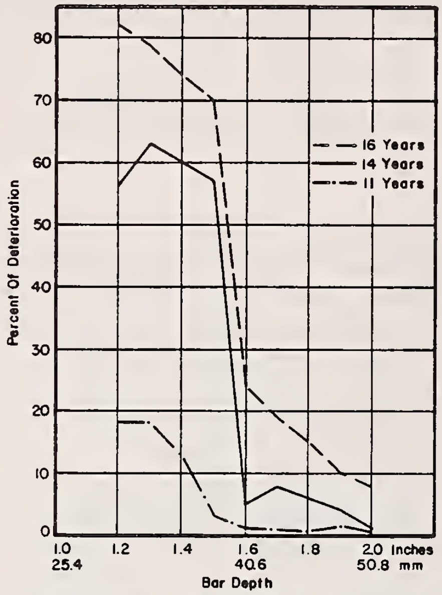

FIGURE 85 REINFORCING BAR DEPTH AS RELATED TO THE PERCENTAGE OF DETERIORATION

Corrosion preventive techniques are to varying degrees unproven. If the corrosion preventive techniques fail then corrosion prevention reverts to the capacity of the underlying construction to resist chloride penetration; for instance.

A membrane or chloride resistance layer may serve negative, as well as positive ends.

Unless care is exercised with the concrete product these top dressings can become a means of merely hiding an "inferior product." The only end result would then be an increase in cost without a corresponding increase in longevity. Furthermore, we feel that if good quality concrete is not possible because of the workmanship then those responsible for that workmanship are not too likely to place a top quality interlayer membrane and overlay. Top quality is needed from the bottom up not merely on the top alone [296].

Detection Systems [287], [324], [389], [397], [409], and [411]

Maximum functional return on funds allocated for structural renovation can, in part, be insured through early detection and repair of structural deterioration [300]. This is particularly true for bridge decks where depacification has occurred and delamination may or may not have been initiated. Early detection of depacification permits the application of neutralization procedures (flushing, cathodic protection) before delamination can occur. When delamination has occurred the delaminated surfaces may be bound back together by gluing [325].

With the possible excepting of cathodically protected decks, any deck that is programmed for permanent repair should also be waterproofed. Whenever an existing deck is to be waterproofed, all the concrete in areas bounded by depacified steel must be removed, as well as all areas having chloride concentrations in excess of 1.18 kilograms of chloride per cubic meter (2 lbs./cu. yd) of concrete. A substantial number of reports have indicated that when this precaution has been ignored, or the remedial action did not address the cause as well as the effect, depacification of the steel in the unremoved portions of the deck has occurred and spalling has eventually returned [263].

Presently the tools and procedures avaiable to the bridge maintenance engineer for evaluating the current condition or the extent of deterioration of a bridge deck include:

1. Potential measurements of reinforcing steel [263], [305], [324], [315], [326], [284], [266], [298], [303] and [327].
2. Delamination detection [263], [328], [303], [329], [330], and [331].
3. Chloride analyses [332], [263], [266], [333], [303], [265], and [334].
4. Nondestructive measurements of concrete and construction quality (acoustic velocity, Windsor probe, Schmidt hammer, pachometer, microseismic refraction) [263], [276], [335], [300], [287], [329], [336], [328], [303], [329], [305], [324], [315], [326], [284], [266], [298], [333], [265], and [330].
5. Subjective visual assessments.

Proper and reliable evaluation of bridge decks both impending and after deterioration processes have occurred is a topic of priority research needs [265].

Potential measurements in addition to determining the locations where steel is corroding, and the classification of corrosion activity of the steel according to the percent of corrosive potentials may also be used to determine the effectiveness of a repair method.

> *Because of the large number of structures that have been exposed to deicing salts, it is obvious that research techniques must be streamlined to operationally determine the methods of repair and/or preservation of the decks. Except for special cases, there are simply too many bridges and too few people and*

> *dollars to spend a long period of time to thoroughly evaluate each structure* [265].

Membranes [337], [338], [263], [339], [340], [341], [342], [343], [344], [345], [346], [270], [347], [348], [349], [350], [351], [352], [353], [392], [401], [402], [405], [406], and [418].

A 1974 memorandum from the Utah Department of Highways to Division eight of the Federal Highway Administration, summarized the present thinking in Utah on membranes and membrane applications. Following are some summary excerpts from this memorandum:

"A waterproofing system that functions well in one area of the country does not mean that it will work somewhere else even under seemingly similar circumstances. This may be the result of different construction practices, materials, environmental or undetermined factors."

"Manufacturer's recommendations for tests such as cold bend and certain material qualifications should only serve to generally describe a product. Most frequently they attempt to eliminate a competitor on an unrealistic technically. Two examples are: 1) whether a two and a half centimeter (1 inc.) strip of material 15 centimeters (6 in.) long is bent 180° over a 1 cm, 1.3 cm or 2.5 cm (3/8", 1/2" or 1") mandrel at -18°C (0°F) or -23°C (-10°F) is meaningless in this instance; 2) if roofing felt is used whether it is 19 or 24 kilogram (50 or 65 lb) should not matter; more applicable would be its quality and contribution to the functional capability of the protective system."

"No membrane should be used on sharp curves, steep grades or where severe braking action occurs."

"Strict temperature requirements should be adhered to on both the high and low sides for placement of the membrane as well as the overlying asphaltic concrete."

"Asphaltic concrete overlays should be thick enough (plus two inches) to protect the membrane. Gradation and type of aggregates in the bituminous overlay should be such that the membrane is not punctured. Plant mix seals should not be placed directly over a membrane."

"Membranes should be applied under the supervision of engineers and inspectors familiar with membrane application. Also, membranes should only be applied by skilled workmen."

"Any membrane or overlay failure should be corrected immediately and its cause defined. A minor failure of either the membrane or overlay can lead to rapid disintegration and loss of the bridge deck protective system."

In general, membrane performance has been good to fair, with isolated areas of failure. It is recognized as a necessity to provide some degree of protection to the concrete deck; however, the search for a more durable, less expensive, alternative method is continuing.

The bonding ability of membranes should be of prime consideration.

In 1972 the Organization for Economic and Community Development (O.E.C.D.) published a report on Waterproofing of Concrete Bridge Decks [270]. The following excerpts from that report describe the requirements to be considered, as well as the attributes and deficiencies of the various approaches:

> *The provision of a waterproofing system is now required by many authorities responsible for highway bridges, particularly for underbridges on roads which are likely to be treated regularly with de-icing salt in winter. The trend towards heavier vehicles and higher stresses in the concrete and reinforcement, associated with the use of more slender designs increases the need for the protection of the deck against damage. Both reinforced and prestressed concrete structures are susceptible to damage and need protection.*
>
> *Effective waterproofing has the added benefit of preventing water from dripping through the deck and causing a nuisance or hazard to users beneath, particularly during frost. It will also avoid unsightly staining of the structure and the formation of stalactites and other lime deposits. The waterproofing is thus an essential component of the drainage system of the bridge deck.*
>
> *For the reasons given above, (provision of) an effective waterproofing layer is an essential requirement for a bridge deck wherever the climate in winter is cold and wet and particularly where de-icing salt is applied frequently.*
>
> *It is difficult to produce an effective waterproofing layer on a roughly finished concrete deck and it is necessary to specify both a tolerance on the profile of the surface and a surface texture which will suit the waterproofing material to be used. More attention needs to be given to the finish to the concrete deck both during the design of the bridge and during its construction.*

During the past years there has been an intensive effort by the Federal Highway Administration (FHWA), state highway agencies and private industry to solve the bridge deck deterioration problem. Richard E. Hay presented a summary of these efforts in the March 1976 issue of Public Roads [424], In considering advantages and limitations of solutions to the bridge deck deterioration problem caused by corrosion, their potential for alleviating any possible freeze-thaw problems that may be present must also be considered. Potential solutions were classified into three categories; 1) Keep the salt (chloride ion) out of the concrete, 2) Keep the chloride ions from the rebar and 3) Control the corrosion. Advantages and limitations of solutions are summarized as follows [424]:

- *Waterproof Membranes*

  Waterproof membranes are presently the most widely used method of protecting new bridge decks from further contamination [425, 426]. *However, there is considerable controversy about the proprietary of placing them over decks in which active corrosion if the reinforcing steel is taking place. Also, construction and maintenance problems are associated with their use.*

- *Surface Polymer Impregnation*

  Surface polymer impregnation is an emerging solution which would provide the same type of protection as a waterproof membrane. At least two applications have been completed. At its current state of development, surface impregnation is initially more expensive than waterproof membranes. It has the potential to provide lasting protection with one application and to provide a very durable concrete surface from the standpoint of abrasion as well as freeze-thaw durability. A disadvantage is that any cracks which may develop in a deck after treatment may require some maintenance in order to guarantee a salt-free structure. However, the use of surface impregnation to prevent further chloride-ion contamination of an existing deck would greatly minimize the cracking problem.

- *Totally Impregnated Precast Panels*

  Totally impregnated precast bridge deck panels are an emerging solution for new construction or for use on bridges where total replacement of the deck is selected as the method of repair [427]. *To date no decks have been constructed using such panels. Decks have been constructed using ordinary precast concrete panels. Present estimates indicate that totally impregnated precast panels may not be capable of competing with other possible solutions in normal construction. However, where reconstruction must be done as expeditiously as possible, particularly in urban areas, pre-cast PIC panels may be less expensive than conventional techniques when the cost of traffic control and providing detours is considered.*

- *Internally Sealed Concrete*

  Internally sealed concrete (concrete in which the capillary and void system is blocked at numerous points with wax) is the newest approach to providing an impermeable concrete.

It could be used for new construction, as a waterproof overlay on an existing deck, or as a reconstruction material where complete replacement of critically contaminated concrete is the repair method. This material has the potential to compete cost-wise with any of the other techniques presently used. The raw wax is relatively inexpensive; there are no apparent problems with mixing it in the concrete; and fusion of the wax can be accomplished with presently available equipment.

Internally sealed concrete also provides a freeze-thaw resistant deck surface. Barring unforeseen problems, it may well become the most useful solution for new construction.

- *Latex Modified Concrete*

  In the second group of solutions, those that keep chloride ions from coming in contact with the reinforcing steel, the most widely used approach is latex modified concrete. This material has a relatively long and successful history as a repair material but has only recently been used on new construction. Presently, it is more expensive initially than waterproof membranes. However, it has the advantage of performing more satisfactory on grades in excess of four percent and in areas where the pavement surface is subjected to shearing forces created by rapid changes in the velocity or direction of vehicles. It may also have the advantage of requiring less maintenance.

- *Epoxy Resin-Coated Rebars*

  Epoxy resin-coated reinforcing steel has been tested on a significant number of bridges. Thus far its cost seems to be highly variable as is the incidence of manufacturing problems. This approach offers an alternative to the bridge designer. It is, of course, viable for only new construction or total reconstruction. A disadvantage is that it does not improve the freeze-thaw durability of the concrete. Consequently, if a quality concrete is not obtained, the value of the coated steel may be lost. A very good application may be in precast units where corrosion protection is required but the use of polymer impregnated concrete or internally sealed concrete is impractical.

- *Three-inch concrete Over Steel*

  An emerging solution is to provide three inches (76 mm) of clear cover over the reinforcing steel. This is particularly attractive where it is possible to place a low water-cement ration concrete (0.35 or less) that is highly impermeable to *chloride ion. However, the number of places where such a concrete can be specified are limited unless special construction equipment or the new water reducers are used. The arbitrary use of thicker cover without specifying the indicated low water-cement ratio concrete and positive control of the degree of consolidation is of very doubtful value.*

- *Galvanized Reinforcing Steel*

In the third group of solutions, those which attempt to control the corrosion or stop it after it is started, the most widely used solution to date is galvanized reinforcing steel. As the zinc corrodes the degree of protection this approach provides is presently unknown. There are structures in Bermuda where it apparently is providing satisfactory long term protection. On the other hand, some research data indicate that such long term protection cannot be depended upon [428]. *Galvanized rebars have been used in a number of bridges, but not long enough to determine their ultimate worth. Although the two should not be compared on a direct basis as they are entirely different products, galvanized steel is less expensive than epoxy-coated reinforcing steel. Galvanized reinforcing steel, like epoxy resin coated steel, does not improve the freeze-thaw durability of the concrete.*

- *Cathodic Protection*

Arresting corrosion of reinforcing steel cathodically by impressing a current on the steel through a conductive overlay is perhaps the newest approach that has been received widespread interest by the highway community. This method, could be used on new bridges as well as on those that are already on the highway system. However, based on its cost compared with other potential solutions for new construction, it appears that its best use would be on existing bridges that are critically contaminated with chloride ions and very difficult to reconstruct. One distinct disadvantage is that the conductive overlay and its attendant wearing course may act as a mulch thereby keeping the deck moist or wet with salt solution. The result could be aggravation of any potential freeze-thaw deterioration problems. Consequently, a careful evaluation of the freeze-thaw durability of the deck should be made prior to application of this method of repair. Such an evaluation on existing decks should include linear traverse measurements of the entrained air void system to determine void size and spacing as well as total air content.

- *Electro-Chemical Removal of Chlorides*

An electro-chemical method for the removal of chloride ion from hardened portland cement concrete has been developed by

Battelle under an FHWA research contract. However, at present it is not known how practical the method will be for field use. Provided the technical problems can be overcome, it could have potential as a method to rehabilitate existing decks that are critically contaminated with chloride ion.

- *Deep Polymer Impregnation of Existing Decks*

Deep polymer impregnation of existing bridge decks is another laboratory development by Lehigh University under an NCHRP contract. This effort differs from surface polymer impregnation previously discussed as it is directed toward the polymer impregnation of all critically contaminated concrete around the top mat of reinforcing steel, and thereby arrests any corrosion of the steel by cutting off the supply of oxygen and moisture required to support corrosion. This differs from previously discussed surface impregnation which is used only as a method to keep chloride ions out of new or rehabilitated concrete.

- *Rebonding With Epoxy Resins or Polymers*

Epoxy resin rebonding has been used for rebonding delaminated or cracked concrete whereas polymer rebonding has been directed toward the in-situ reconstitution of totally deteriorated concrete. Epoxy resin rebonding of delaminated concrete along may not offer a permanent repair. However, when used in conjunction with cathodic protection, it does offer an excellent potential for permanence. Injecting epoxy resin into cracks such as are found in delaminated bridge decks is a practical process, and a number of private firms now specialize in this type of work on a contractual basis. Polymer rebonding of totally disintegrated concrete is not yet a routine field process. The technique has been demosntrated to be feasible on a small scale, and a full-scale bridge repair is planned by the New York Department of Transportation. It has the potential to offer a totally new method of repair that would not require removal and replacement of deteriorated bridges with the attendent traffic problems of such repair methods.

Maintenance [354], [355], [356], [388], and [396]

Specific aspects such as salting, plowing, and deck repairs are typically thought of as maintenance activities and are discussed here.

Salt has been shown to be an agent required and partially responsible for both reinforcing steel depacification with its subsequent delamination and spall damage; and differential freezing of the wearing surface with its resultant scaling.

Both categories of damage can be significantly reduced by effective deck waterproofing procedures. In areas where waterproofing has not been incorporated into the deck; the initial decision to use deicing chlorides should account for this.

A publication by FHWA [305] showed that the equivalent of seven applications of sodium chloride (at 169 kg per 3-2/3 lane kilometer or 600 lb/12' lane mi) were sufficient to initiate depacification of steel in some test slabs, and that the equivalent of 28 applications had depacified steel in all of the test slabs. The decision regarding the feasibility of substituting an alternate deicing chemical is probably best decided on an individual case basis.

In an article by J. C. Kliethermes published in 1972 [269], the following points are made:

> - *Annual maintenance costs do not adequately indicate the scope of the problem. Most states that have a severe problem would spend more if funds were available.*
>
> - *Some states have areas of severe deterioration and areas of light or no deterioration. This complicates any attempt to show general affected locations.*
>
> - *The scope is changing rapidly. Many states indicate that both the cost and the number of bridges requiring maintenance are increasing.*
>
> *After evaluating all conditions, we arrived at the following conclusions. The severe, moderate, and light problem locations fall into geographical areas. There is, of course, no distinct division line, and some overlapping will occur. Based on spot checks within these areas, it was estimated that the national cost of repair for decks in 1971 was more than $40 million* [269].
>
> *The challenge of what can be done to keep this cost at a minimum falls into two categories:*
>
> - *Establish an effective and permanent repair procedure for existing decks, and*
>
> - *Develop a technique that will prevent the problem from reoccurring by a change in new designs.*
>
> *Extensive research is under way in both areas. This research includes the use of polymers in concrete,* [363], [364], [365], [392], [398], and [418]

> [366], [367], [368], [369], [370], [371], [372], [373], [374], [356], [375], [268], [376], and [377] *protective coatings for reinforcement,* [378], [379], [380], [381], [382], [383], and [384] *and cathodic protection* [385], [378], [265], and [387].... *It is the opinion of many researchers that, once the corrosion cell has started, it will continue, and no corrective treatment, short of total removal, will be effective....*
>
> *An informal survey conducted with the demonstrations indicated that a large variety of methods and techniques are being used to patch deteriorating decks* [342], [303], [357], [358], [359], [360], [361], [362], [404], [407], and [415]. *However, we have little confidence in any one method, and, without complete surface or total deck removal, no effective permanent repair method was found.*

Many patching methods and/or patch materials do not protect the steel against corrosion and may accelerate the rate of deterioration. Because of this acceleration, an elaborate and costly patching procedure may only provide a temporary repair. Accelerated deterioration results from patching materials that are designed for rapid strength gain but that contain additives such as chlorides or other set accelerators that are highly corrosive to steel. Patching materials may create strong anodes, and corrosion begins in the patch area soon after placement. The opposite is true when concrete is removed from a spalled area in a salt-contaminated deck and replaced with concrete that does not contain set accelerators. The new patch will be free of chlorides and will create a differential environment corrosion cell. The repaired area will take the position of a strong cathode and create a large potential difference between the patch and the remaining portion of the deck. This potential difference will cause a current flow resulting in accelerated deterioration.

The probability of successful maintenance can be increased by removing the concrete that surrounds active steel. In many situations, this will require total deck removal. Funding limitations and common practice often restrict this approach. In these situations and where the deck is of acceptable quality (even though active corrosion is suspected throughout the deck), a method used by California State to repair bridge piers in a marine environment can be applied to deck patching. Theoretically, the reinforcement bar in the area of the patch can be eliminated from the corrosion circuit.

No repair methods are considered to be foolproof and therefore should be tested under local conditions.

> *... In summary, the highway engineer is challenged to provide a transportation facility 24 hours per day, 365 days per year. De-icing salts have proved to be an effective maintenance tool in meeting this challenge. We are now*

challenged to find an economic solution to what appears to be a costly secondary effect.

Bridge deck spalling is not a local problem. All indications are that the affected geographical area will increase in size with a corresponding increase in cost [269].

APPENDIX

STATE	LEVEL OF EFFORT AND/OR LEVEL OF SERVICE - Guidelines and/or Standards
ARIZONA:	Class — Estimated Average Plowing Speed — Planned Maximum Accumulation A — 25 M P H — 1 inch B — 20 M P H — 2 inches C — 10 M P H — 6 inches More plows assigned to higher priority roads than lower priority roads. This is done by increasing the number of miles in each plowing route assignment as the priorities become lower - 1 man plow crews. Cinders and Salts applied on hills, curves and icy spots. Plowing frequency depends on Class and specific need.
CALIFORNIA	Road Class A: Snow removed continuously during storm to keep roads open for traffic and provide a good surface on which to operate except when visibility or avalanche danger make conditions too hazardous. On highways with four or more lanes, two lanes in each direction kept open during storm. Clearing remaining lanes and shoulders done during regularly scheduled shifts after the storm ends. Chain requirements removed and bare pavement achieved as soon as possible following the end of storm. Patrols established for areas where conditions require surveillance of the roadway for ice, avalanche or snow. Chemicals or abrasives or a combination applied to enhance traffic safety when deemed necessary by the maintenance supervisor. Road Class B: This level is the same as for "A" except that chain requirements should be removed and bare pavement achieved within 48 hours following the end of storm. Road Class C: Snow removed during the storm to keep roads open to traffic. Snowpack left by truck plows not removed until a thawing condition exists or pack becomes so thick as to constitute a traffic hazard when it thaws. Removal of pack and widening done during regularly scheduled working hours. Patrols established for areas where conditions require surveillance of the roadway for ice, avalanche or snow. Chemicals or abrasives or a combination applied to enhance traffic safety when deemed necessary by the maintenance supervisor. Road Class D: Snow removed only during regular working hours except that some routes may be plowed at any time when the District Director determines there is sufficient reason for plowing. Some routes may be allowed to close during moderate to heavy snow storms when the District Director determines this is the proper course of action. Roads allowed to close temporarily will be reopened after the end of storm during normal working hours as equipment is available. Once open, the road should be treated with chemicals or abrasives or a combination to provide for traffic safety as deemed necessary by the maintenance supervisor. Road Class E: These routes are allowed to close during the winter and are reopened in the spring when it is reasonable to assume the storm possibilities are over.
CONNECTICUT	Two men are assigned to each truck. On two-lane highways, two trucks are assigned 16 miles: on four-lane highways, three trucks are assigned 10 miles, and on six-lane highways, five trucks are assigned. One truck is assigned approximately five miles of ramps. Two-Lane Highways: Spreading assignments for two-lane roads entail two separate runs within the overall limit of the echelon plowing run. Two trucks equipped to deposit snow to the right will meet at a pre-designated spot and commence plowing in echelon to the end of the assigned run. At this point both trucks turn around and proceed to plow the other half of the roadway, continuing without interruption. Multi-Lane Highways: Trucks designated to do echelon plowing on multi-lane routes are assigned specific sections of a run for the application of snow and ice control materials when required. Upon completion of the application of snow and ice control materials, trucks line up at a pre-designated spot and commence plowing in echelon. Unless there is limited space or some other restraint, the first truck on 4-lane highways and the first two trucks on 6-lane highways of the echelon group will deposit the snow to the left. The remaining trucks will plow the snow to the right with the intent that the entire width of travelway will be cleared of snow by each pass of the plow train. One truck will be used to plow ramps within an assigned zone. Policy is to accomplish round trips with sufficient frequency to maintain the travelway and ramps in a snow-free condition.

STATE	LEVEL OF EFFORT AND/OR LEVEL OF SERVICE - Guidelines and/or Standards
DELAWARE	Bare pavement maintenance. Strive to obtrain this for the traveling public using all the tools at our command.
IDAHO	Plow as snow falls - in all areas this will not allow over 3 inches of snow before plow removes. Chemicals are used primarily in conjunction with sand to keep it from freezing in hoppers. Snow removal equipment is assigned to snow areas on the basis of need and should be commensurate with requirements. In territories of light snow fall, trucks equipped with push plows will normally suffice, in other territories where snow removal is a routine winter procedure, regular snow removal equipment, motor graders, and snow plows are provided.
ILLINOIS	The level of effort is largely determined by the manpower and equipment assigned to the snow routes on different type pavement. Urban Expressways (highest service); effort controlled by manpower and equipment available. Interstate; three trucks per snow route (1 hopper body tandem). Four-lane primary; two trucks per snow route. Two-lane primary; one truck per snow route. (Most trucks are 3 ton dumps. A few special units such as 4-wheel drives are available. Manpower is sufficient to run alternating 12 hour shifts around the clock when needed). Chemicals are ordinarily used on all State maintained pavements. Cycle times do not very appreciably. When conditions are severe, men and equipment may concentrate on keeping the major routes open at the expense of lower traffic highways. If salt is in short supply it may be reserved for the major routes.
INDIANA	Class I: Reasonably bare pavement in all driving lanes. Pavement surface plowed if more than 1 inch accumulation (frequency - every 2 hours). Final cleanup in normal working hours. Class II: Reasonably bare center portion with at least one wheelpath in each direction free of ice and snow. Pavement surface plowed if more than 1 inch accumulation (frequency - every 3 hours). Final cleanup in normal working hours. Class III: Plow only as required to obtain passable conditions. (Frequency - every 4 hours). Chemicals will be used only for spot treatment of hills, curves, and intersections in cleanup operations.
IOWA	It is the objective to sustain a work force capable of achieving the following for the normal range of storm conditions: (1) A reasonably near normal bridge deck surface condition within the hour after first notice of frost on both priority 1 and priority 2 highways. (2) A reasonably near normal surface condition within 10 hours after a storm ends, on priority 1 highways. (3) A sufficiently bare inside wheelpath as to provide traction within 24 hours after a storm ends, on priority 2 highways. (4) Clean shoulders on priority 1 highways within 3 working days after a reasonably near normal surface is attained, working regular hours. (5) Clean shoulders on priority 2 highways as time permits during regular working hours. It is expected that field maintenance garage locations will be staffed, equipped, trained, and organized to fulfill the capability of treating the normal range of storm conditions within the time frame outlined above. It is further anticipated that this work force will be adequate to treat freezing rain and sleet conditions that may occur independently of any other storm. When the storm has ended, the surface should be returned to specified service level conditions as quickly as possible.
KANSAS	Personnel shall be assigned to the 12 hour shifts outlined in the storm coverage plan. Emergency labor may be hired when necessary. With the first precipation and falling temperatures the trucks should begin patrolling their assigned areas. Abrasives are applied to bridge decks, hills, curves, junctions and surfaces at stop signs (approximately 10-15% salt). If necessary, a light application of this material may be applied to all roadways. During a storm, snow is bladed to bare pavement and abrasives are applied to slick areas. Snow removal operations are continuous except during extreme blizzards. After the storm has receded, precipitation stopped, and with rising temperatues, a mixture of 75% salt and 25% calcium chloride will be applied to the areas of packed snow and ice which remains. Blading will be continued following treatment until snow pack and ice are removed. Priority 1 roads will be cleared of ice and snow by plowing and complete salting (if necessary). If complete clearing is not possible, abrasives may be used to effect the safe movement of traffic.

STATE	LEVEL OF EFFORT AND/OR LEVEL OF SERVICE - Guidelines and/or Standards
KANSAS (Cont)	Priority 2 and 3 roads should be maintained in a safe, passable condition by plowing and applying salt and/or abrasives. The maintenance foreman is responsible for adherence to the priorities on snow and ice removal operations. Priority 4 roads should not receive complete salting except those sections which serve heavily populated and industrialized areas and/or carry a heavy volume of traffic. These roads should not be plowed except during regular working hours or by specific authorization by the District Office. Salt may be applied and overtime work may be authorized by the Foreman at specific locations, such as steep hills, dangerous curves, icy bridge decks or hazardous intersections.
MAINE	Have attempted bare pavement policy on all routes - frequency with type of storm. (Some northerly routes snow covered and sanded only, approximately 5% of total mileage.)
MARYLAND	The use of chemicals or abrasives and the plowing frequency is determined by the type and severity of the storm and the magnitude of the recovery effort is also determined by the type and size of the storm in progress. Of the 5,200 miles of highways, 3,140 are snow emergency routes of which 2,740 miles are carried under the bare pavement program. State owned snow equipment can be augmented by hired equipment and personnel to whatever degree necessary. The Maintenance Division is committed to keeping this entire system open with priority on snow emergency routes. When snow fall has ceased, the pushing back and dressing up operations continue until the entire system is "Bare Pavement."
MASSACHUSETTS	Plowing operations start as soon as there is a plowable depth of snow and the operations shall continue for the duration of the storm and until all pavements and shoulders including acceleration and decleration lanes are reasonably clear. Wherever possible, plowing is done by trucks operating in echelon. Widening should be done in one operation, if possible, to avoid the repeated piling of windrows at driveways and intersections. Four-wheel drive units are used for widening and winging back. Whenever possible, heavy duty work should be restricted to the use of four-wheel drive trucks.
MICHIGAN	Plowing frequencies average 1-1/2 to 2 hours per cycle. Plowing or blading with truck underbody scrapers bring snowpack to less than one-half inch. Salting removes snowpack to bare pavement. During severe snowing and blowing conditions the snowpack is sanded on hills and curves to provide some degree of wheel traction for the motorist. On first priority roads, a continuous effort is expended to bring the pavement to a bare wet condition without any restriction on overtime. Second priority roads, a continuous effort is expended to reach a bare, but wet, center eight feet of pavement. When this condition is reached and is likely to sustain itself, overtime work will cease. Pavement is brought to a full bare condition during regular working hours. Third priority roads are plowed, but left snow-covered when overtime work will cease. Roads are brought to a bare pavement condition after the storm and during regular working hours. Equipment operator staffing varies from 1.6 to 2 men per truck route. Winter maintenance services are planned on a 24-hour basis. Heavy staffing is in areas where long extended storms are more common. The same equipment and manpower is used for all levels of effort. The only difference is the amount of overtime which will be worked to obtain a minimum road condition.

<table>
<tr><th>STATE</th><th>LEVEL OF EFFORT AND/OR LEVEL OF SERVICE - Guidelines and/or Standards</th></tr>
<tr><td>MINNESOTA</td><td>
All attempts will be made to provide the following:
<table>
<tr><th>Classification</th><th>ADT</th><th>Level of Service*</th><th>Coverage Time**</th><th>Cycle Time***</th></tr>
<tr><td>(1) Urban Commuter</td><td>Over 10,000</td><td>Bare pavement within 6 hours after termination of storm (12 hours for severe storms).</td><td>24</td><td>2</td></tr>
<tr><td>(2) Rural Commuter</td><td>2,000-10,000</td><td>Bare pavement within 24 hours after termination of storm. (On divided highways, left lanes should be half bare with sanded curves and hills before termination of snow removal effort.</td><td>18</td><td>3</td></tr>
<tr><td>(3) Primary</td><td>800-2,000</td><td>Clear wheel tracks with bare pavement on hills and curves. Compacted snow with appropriate sanding permitted in towns.</td><td>18</td><td>4</td></tr>
<tr><td>(4) Secondary</td><td>400-800</td><td>Bare left wheel track in each direction plus bare centerline, sanded hills and curves.</td><td>12</td><td>8</td></tr>
<tr><td>(4) Secondary</td><td>250-400</td><td>Bare left wheel track and sanded hills and curves.</td><td>12</td><td>8</td></tr>
<tr><td>(4) Secondary</td><td>Under 250 & Gravel Roads</td><td>Compacted snow is acceptable.</td><td></td><td></td></tr>
</table>
<p>(1) Urban Commuter - One section crew per 30 Lane Miles; (2) Rural Commuter - One section crew per 45 Lane Miles; (3) Primary - One section crew per 60+ Lane Miles contingent upon roadway terrain.</p>
<p>A normal section crew consists of two men equipped with either a single axle or tandem axle end dump truck rigged with a plow and sander. Normally snow plowing is considered a one-man vehicle operation, except when winging is required which is a two-man vehicle operation.</p>
<p>* Based on an average snowstorm of four inches falling in six to eight hour period. Standards apply only to the mainline and interchange roadways; frontage road, crossover and other cleanup operations are not included.</p>
<p>** Coverage time is defined as number of hours per day that service will be provided during the storm.</p>
<p>***Cycle time is defined as the amount of time allowed to remove snow on through lanes of a given route section while providing the specific level of service under average conditions.</p>
</td></tr>
<tr><td>MISSOURI</td><td>
<p>On all routes plowing begins and continues if there is 1/2 inch of snow on the pavement. Continuous treatment with chemicals is done on interstate, urban and routes with an ADT of 1000 or over. On other routes hazardous areas such as hills, curves and intersections are treated with chemicals as needed.</p>
<p>In general available manpower and equipment are applied whenever conditions warrant action. Exceptions would be very light or intermittent storms when skeleton crews patrol areas to spot hazardous areas.</p>
</td></tr>
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<table>
<tr><th>STATE</th><th colspan="5">LEVEL OF EFFORT AND/OR LEVEL OF SERVICE - Guidelines and/or Standards</th></tr>
<tr><td>MONTANA</td><td colspan="5">1. One man, one plow, one sander per 20 lane miles. Continuous from beginning of storm period through cleanup. Sand curves and hills, first then tangents as time permits.
2. One man, one plow, one sander per 40 lane miles. Continuous through storm and cleanup during period of heaviest traffic-approximately 6 a.m. to 10 p.m. Sand curves and hills first, then tangents as time permits.
3. One man, one plow, one sander per 60 lane miles. Once or twice daily - sand curves and hills.
4. Serviced when manpower or equipment available. As time allows.</td></tr>
<tr><td rowspan="5">NEBRASKA</td><td rowspan="2">Highway Classification</td><td colspan="2">Coverage Time (Hrs.)</td><td rowspan="2">Cycles 8 Hr. Shift</td><td rowspan="2">Level of Service</td></tr>
<tr><td>Drifting Conds.</td><td>Icing and Snow Pack Conds.</td></tr>
<tr><td>Interstate and over 3000 ADT High Volume</td><td>24</td><td>24</td><td>4</td><td>Bare pavement as soon as practical after termination of storm. Chemicals and sanding may be used, at the option of the district engineer, to obtain this level of service. Crews would be split and work 12-hour shifts until finished.</td></tr>
<tr><td>Primary 800 - 3000 ADT</td><td>24</td><td>18</td><td>2</td><td>Bare wheel track in each lane as soon as practical after termination of storm. Sanding as needed to improve traction on hills, curves, and stop signs. Chemicals may be added to sand if conditions are so severe that normal sanding will not accomplish the bare wheel track in each lane. Crews will be split to accomplish required coverage. The numbers of men and equipment per operating shift is a function of the weather conditions and shall be determined by the district engineer. Overtime may be used, but kept to a minimum consistent with accomplishment of aboved mentioned policy.</td></tr>
<tr><td>Secondary Under 800 ADT</td><td>24</td><td>10</td><td>1</td><td>One lane will be cleared and kept passable during and following heavy snow conditions. Crews will be split to accomplish required coverage. Sanding of bridges and intersections may be performed to alleviate dangerous conditions. Chemicals would not be used. Overtime may be used, but kept to a minimum consistent with accomplishment of the above mentioned policy. Cleanup will be during 8-hour shift.</td></tr>
<tr><td>NEVADA</td><td colspan="5">Follow the snow and ice control plan instituted in each District. Remove snow from the pavement surface for the full width of the traveled way. Widening to provide storage space and additional paving to provide bare pavement should not be done on overtime. Spread sand or salt-sand mix to increase skid resistance and facilitate ice and snow removal.
All is done according to the snow plan and schedule prepared by the District. Plowing with truck mounted plow - includes the following actions: plowing snow on the traveled way, ramps, interchanges, turnouts and access to sand and salt storage areas.
The amount of snow and ice control equipment on the traveled way is determined by the severity and prolongation of the storm and is ordered by the supervisor in direct charge of the operation.</td></tr>
</table>

<table>
<tr><th>STATE</th><th>LEVEL OF EFFORT AND/OR LEVEL OF SERVICE - Guidelines and/or Standards</th></tr>
<tr><td>NEW HAMPSHIRE</td><td>
<table>
<tr><th>Type of Highway</th><th>Plowing Frequency</th><th>Depth of Snow</th><th>Chemical Chemical</th><th></th></tr>
<tr><td>Interstate</td><td>Hourly</td><td>1 inch</td><td>Yes</td><td>One plow truck per each 10 lane miles of main line, plus one plow truck for each two interchanges.</td></tr>
<tr><td>Primary</td><td>2 Hours</td><td>2 inches</td><td>Yes</td><td rowspan="3">Varies from an average of one plow truck per 10 lane mile in the more heavily developed southern sections of the State to one truck per 20 lane miles in the sparsely settled northern section of the State.</td></tr>
<tr><td>Secondary</td><td>2 Hours</td><td>2 inches</td><td>Yes</td></tr>
<tr><td>Secondary Under 400 ADT</td><td>3 Hours</td><td>3 inches</td><td>Some with Sand</td></tr>
</table>
</td></tr>
<tr><td>NEW JERSEY</td><td>Approximately 9 trucks and 9 drivers per each 75 lane miles. Continuous plowing - we try not to have a snow pad. Each Regions is adequately staffed with personnel, equipment and contractors to handle forseeable winter emergencies. The foreman is authorized to take such action as is necessary for the removal of snow from the road surfaces and/or for the alleviation of roadway icing conditions, and is responsible for proper scheduling of men and equipment so as to insure an efficient operation. He shall apply his knowledgeable experience in the section of both material mixes and application rates within limits of operational guidelines to properly maintain his assigned roadways during a storm and to achieve bare pavement in accordance with Departmental policy as soon as practical following a storm.</td></tr>
<tr><td>NEW YORK</td><td>
The present equipment staffing should provide full width pavement ice control for normal storms. For major storms of long durataion use Standards below.
<table>
<tr><th>Highway Priority Class</th><th colspan="2">Snow Depth Plowing Begins(Inch)</th><th>Maximum Snow Depth Allowable (Inches)</th><th>Average Plow Speed (MPH)</th><th>Time Full Width will be clear of snow after Storm. (Hours)</th><th>Minimum Clear Pavement Width</th><th>Within Hours after Storm</th><th>Full Width Clear within (Hrs) After Storm</th></tr>
<tr><th></th><th>Desire</th><th>Max.</th><th></th><th></th><th></th><th></th><th></th><th></th></tr>
<tr><td>A_1 & A_2</td><td>1/2</td><td>1</td><td>2</td><td>30</td><td>1</td><td>Middle 1/2</td><td>4</td><td>12</td></tr>
<tr><td>B.</td><td>1</td><td>1-1/2</td><td>2 1/2</td><td>25</td><td>1 1/2</td><td>Middle 1/2</td><td>8</td><td>24</td></tr>
<tr><td>C.</td><td>1</td><td>2</td><td>3</td><td>22-1/2</td><td>2 1/2</td><td>Middle 1/3</td><td>12</td><td>48</td></tr>
</table>
Pavement should be salted as soon after plowing as possible.

The standard will vary for each residency based on such factors as traffic volume, rate and frequency of storms, population centers, working hours of large employers within the residency, the necessity of maintaining a consistent level of service on important through highways. (1) Minimum standard - Continuous telephone and radio watch at the residency. Necessary additional personnel will be called as conditions warrant. (2) Desirable for residencies with Class A2 and high volume Class B highways - Adequate standby crews during the hours of heavy traffic thereby allowing a few vehicles to be working early in the storm while additional needed personnel are being
</td></tr>
</table>

STATE	LEVEL OF EFFORT AND/OR LEVEL OF SERVICE - Guidelines and/or Standards		
NEW YORK (Cont)	called to work. (3) Desirable for residencies with Class Al highways - Adequate crews 24 hours a day to immediately start snow and ice control procedures on these highways when storm conditions develop. The number of personnel assigned to shift work relate to the classification and amount of the mileage to be serviced. A large amount of high priority lane mileage will require more shift personnel than is necessary in a residency where high priority mileage is a small percentage of the total. The number of shifts that can be provided depends on the operator/vehicle ratio. Points where hazards are acute such as steep grades, sharp curves, bridges and approaches, and railroad crossings are first priority for snow and ice control regardless of the highway classification on which they are located. For the most part, the initial response during a storm and any special attention needed during the storm at these points will be provided by the Foreman over the area.		
NORTH DAKOTA			
	Interstate and High-Volume 4-Lane open to traffic 6 hours after storm - severe storm, as required by conditions. Bare pavement as soon as capabilities allows.	Motor Grader & Underbody Blades: 16 Hours, 1st day; 14 Hours, 2nd day and thereafter with a minimum of 8 hours between shifts. Sanders: 12 hours.	Rountine Areas, 4 Hours; Problem Areas, 2 Hours. Motor Grader and Underbody Blades: As conditions dictate. Sanders: 8 hours.
	High-Volume Primary and Secondary Highways (Approx. 750 ADT and over) Open to traffic 6 hours after storm. Severe storms as required. Bare pavement as soon as allowed.	Motor Grader & underbody Blades: 16 Hours, 1st day; 14 Hours, 2nd day and thereafter with a minimum of 8 hours between shifts. Sanders: 12 hours.	6 hours. Motor Grader & Underbody Blades: As often as possible (Approx. once daily) Sanders: 8 hours.
	Medium-Volume Primary and Secondary Highways (Approx. 750 ADT and 250 ADT). Open to traffic 12 hours after storm. Severe storms as required.	Motor Grader & Underbody Blades: 16 Hours, 1st day; 14 Hours, 2nd day and thereafter with a minimum of 8 hours between shifts. Sanders: After higher priorities are satisfied, then 12 hours.	Indefinite Motor Grader & Underbody Blades: As often as possible (Approx. once daily) Sanders: After higher priorities are satisfied; 8 hours.
OHIO	An average of 25 lane miles per truck. Manpower is adequate for 16 - 24 hours of continuous operation. Interstate routes first priority on snow and ice removal operations. Interchanges rate equal priority with the main interstate road, and equipment dispatched to these interchanges at the same time as the interstate routes. The County Superintendent shall, in case a storm of long duration is predicted, organize relief crews to insure sufficient manpower for continuous operations. Contractors' equipment may be rented as needed. Snow Removal: Chemicals applied to pavement as soon as the snow starts to accumulate. Plowing starts as soon as snow or slush reaches sufficient depth to warrant. Plowing operations shall be delayed long enough to allow the chemicals to work; however, slush shall not be permitted to refreeze on the pavement. Plowing back and cleanup operations start after the pavement has been cleared and the storm has abated. Plows move the windrow of snow as far back on the shoulder as practical. Equipment is assigned to clean up side roads and mailbox approaches and crews begin removal of snow and ice from bridges, catch basins, and clogged inlets. Ice Control: Patrols and crews provide early treatment for bridges and critical danger spots, including curves, steep hills, intersections, railroad crossings, hidden drives, and narrow or steep bridge approaches. It is suggested that chemicals be used to produce a bare pavement (within a reasonable time) on all priorities except low volume fourth priority roads, which shall be treated at hazardous locations with chemically treated abrasives.		

STATE	LEVEL OF EFFORT AND/OR LEVEL OF SERVICE - Guidelines and/or Standards
OKLAHOMA	Priorities are given to Interstate and other heavily traveled roads where the bulk of traffic is being detained. The majority of snow and ice equipment serves as dual purpose with the snow plow attachments used on the same equipment as used for routine maintenance. The same manpower is utilized for snow and ice and routine maintenance, with emphasis placed on snow and ice during these winter conditions.
PENNSYLVANIA	Assignments for truck equipped with plow and spreader are: First Priority Routes - from 20 to 30 lane miles. Second and Third Priority Routes - from 40 to 50 lane miles. The Department has 2100 trucks available for snow removal. This fleet is supplemented with rental trucks to provide sufficient trucks to cover the 45,000 miles of highway. One way traffic may be maintained on third priority routes after first and second priority routes have been opened for two-way traffic. The servicing of third priority roads amounts to removing snow along the entire route and applying anti-skid materials at dangerous locations; however, the use of heavy snow-fighting equipment may be required at times to open such roads, because of severe drifting conditions. Physical conditions which cause a roadway or section of roadway to become immediately hazardous should constitute justification for assignment to a higher priority than might normally be considered. On First Priority Routes, Department policy is to spread 100% chemicals. Spreading width shall not exceed 12 feet on these highways. On Secondary and Third Priority Routes salt, abrasives, or a combination thereof is spread in accordance with the guidelines for application. One spreader truck will normally be used to apply chemicals on two lanes at one time. On three lane roads, if all lanes are in the same direction, one truck will spread the two most heavily traveled lanes. Unless otherwise decided by the District, the low volume traffic lane will not be serviced and then by plowing only, until the snow has reached a depth of 3 inches. When plowing, equipment shall be scheduled to plow 1st priority routes each hour, 2nd priority routes each 1 1/2 hours, and 3rd priority routes as often as possible. Generally, 3rd priority routes will not be plowed between the hours of 11:00 p.m. and 5:00 a.m. and 2nd priority routes will receive little attention during the same hours.
SOUTH DAKOTA	Operations begin when the supervisor feels they are needed and they are continued until the problem is taken care of. Equipment is basically the same for all levels except that they usually will be used on the priority one routes first and then on to the others. CHEMICAL TREATMENT and/or APPLYING SAND or a SAND CHEMICAL MIXTURE to roadway surfaces to reduce slippery conditions and provide at least one bare wheel track in each lane as soon as possible. The sanding and/or chemical treating operation shall be performed in the following sequence: (1) utilize sufficient equipment to sand and/or apply chemicals to the entire length of those highways shown on the current Priority One Route Map. (2) utilize remaining equipment to sand and/or apply chemicals to hills, curves, bridges, highway intersections and dangerous locations on all other routes. (3) sand and/or apply chemicals to service roads, side approaches and local intersections as needed. Repeat applications as needed to meet existing conditions. Keep chemical and/or sanding equipment in operation until all state maintained roads are passable and traffic is moving safely or until no longer effective and are replaced by other operations. Begin plowing or blading when the chemical brine has turned the ice or packed snow into a "slush" or "mulch" condition. Liquid chloride or sand can be used with the chemical mixture, or additional amounts of calcium chloride can be used at any temperature if high speed removal is needed. Sanding and/or chemical treating is an emergency item that shall have priority over all other activities except those pertaining to snow and ice removal. Daily inspections and reports will determine the locations and amounts of sanding and/or application of chemicals necessary to satisfy route priorities. Application of chemicals should be scheduled to begin prior to accumulation of snow and ice when temperatures are such that the chemicals will react. Permission must be obtained from the District Maintenance Engineer or his authorized representative to change the sequence, rates or limits of work as stated in the standard.

STATE	LEVEL OF EFFORT AND/OR LEVEL OF SERVICE - Guidelines and/or Standards
TENNESSEE	The County Foreman have been assigned certain routes and the responsibility of beginning snow operations is placed upon him and the District Maintenance Engineer. When hazardous conditions prevail the Engineer or Foreman will issue a call out to his crews according to the number (based on the lane miles to be covered) he feels necessary to perform the snow and ice removal activities. Interstate Routes are given top priority, and the heaviest travelled State routes are next. However, it is desired that all routes be salted or plowed simultaneously if manpower and equipment is available. The level of effort for a route depends on the condition of that route. If the accumulation is less than one inch salting operations begin. (Two-lane pavement a frequency of once every 3 hours). When the temperature is below -12°C (10°F) abrasives and/or calcium chloride is used. If the accumulation is greater than one inch plowing operations begin.
TEXAS	Begin ice control when ice begins to form on hills, curves and bridges. Begin snow control after accumulation of 2-3 inches or when enough has accumulated to plow. Plowing frequency is as needed and manpower allows. Salt-sand mixture used on bridges, hills and major interchanges in some areas. Use truck mounted snowplows, motor graders and trucks with material spreaders. Manpower is from each maintenance section.
UTAH	The roadway is plowed, sanded, cleared of frost, snow and ice pack and widened as quickly as possible even though this involves working extra hours, nights, Sundays, or legal holidays. The work is prosecuted as vigorously as practicable so that roads are maintained in as good a condition as is possible with the equipment, materials and men assigned to the work. Each highway on the state system is to be provided a designated type of snow removal service. The general treatments to be provided each class are listed below: Class I: (1) Application or brine-producing materials for the purpose of avoiding snow pack conditions. (2) Plowing frequency to insure an accumulation not exceed 1-1/2 inches, generally 1-1/2 hour frequency. Class II: (1) Plowing frequency to insure an accumulation not to exceed 2 inches, generally 2 hour frequency. (2) Application of straight abrasives to hills, curves, icy spots and other hazardous locations. Class III: Planned on an individual basis with treatment pertinent to each situation. Class IV: Closed in the fall when snow depth requires and opened as soon in the spring as feasible. Special Treatment: Ice and snow pack requiring concentrated effort may exceed Class I or II services.
VERMONT	The Department of highways is under a Legislative mandate to maintain a bare and safe road policy, consequently all routes have same priority. Bare road policy dictates that operations begin with first snowfall. Equipment and Manpower needs are: 1 truck for 14 2-lane miles; 1 man for 7 2-lane miles; and 1 loader for 5 trucks. When pavements become snow covered, salting commences, windrowing along the centerline of tangents and as high as possible on banked sections. When snow reaches 2 inches, plowing commences and continues throughout the storm. Following storm abatement a second application of salt is made in a similar manner to bare the pavement until the next storm. Depending upon the type of storm, sanding may also be required on hills, curves, and at intersections.
VIRGINIA	Normal compliment of maintenance men and equipment at area Field Offices are assigned plowing and chemical spreading routes: These forces and equipment are supplemented by other District Staff personnel, as well as, privately hired equipment and operators as needed. In order to carry out snow and ice control operations all roads are classified by priority: Priority One: Length - usually 20 to 25 miles round trip. Time - estimated time under moderate storm conditions 60 to 80 minutes round trip. Equipment - Two-lane, Two trucks in echelon; Three-lane, Two trucks in echelon, if additional truck or motorgrader is available, it is used on the three lane route, but also designated as available for assignment elsewhere if needed; Four-lane, not divided - three trucks in echelon, with truck #3 designated as available for assignment elesewhere if needed; Four-lane divided, Interstate - Three trucks, truck #1 pushing left and trucks 2 and 3 pushing right; More than Four-lane; use four trucks with one or two pushing left and the remainder to the right, supplement with motor grader to push back as needed; Four-lane divided, Arterial, Three trucks, with truck #1 pushing left into median to avoid windrow in traveled way. Truck #1, #2 and #3 should operate independently.

STATE	LEVEL OF EFFORT AND/OR LEVEL OF SERVICE - Guidelines and/or Standards
VIRGINIA (Cont)	Truck #3 designated as available to be moved These routes are kept free of ice and snow so that traffic can proceed in safety without the use of chains, except during periods of heavy falling snow or drifting. Priority Two: Length - usually 25 to 30 miles round trip. Time - estimated time under moderate storm conditions 90 to 120 minutes round trip. Equipment - Two-lane, one truck on the road, supplemented by motorgrader where possible. On these routes snow and ice shall be removed or so covered with abrasives to make travel by chains unnecessary as soon as possible but within 24 hours after the cessation of falling weather. Priority Three: Length - 50 to 75 miles per truck. Time - Estimated under moderate storm conditions 225 to 300 minutes round trip. These routes shall be plowed as soon as possible but within 24 hours after the cessation of falling weather. All hills and trouble stops are covered with abrasives as soon as possible but within 48 hours after the cessation of falling weather. Priority Four: These routes shall be made passable with the use of chains as soon as possible but within 48 hours after the cessation of falling weather. These guides to assignment length and estimated time are basic rules and values for use in planning for plowing. However, it is realized that adjustments to these suggested standard ways of making assignments will be necessary in a number of cases. The primary consideration is to work out plans that provide regular coverage on a reasonable time basis. The one hour frequency established for priority One roads is near the maximum anticipated need, and something a little less than this will be adequate for most storms. The planning process should provide for a higher level of service when required by weather or traffic conditions. Priority One and Two routes are planned in detail for chemicals and plowing. Priority Three and Four are planned for Plowing. Only under very unusual circumstances are chemicals used on Priority Three and Four.
WASHINGTON	The roadway is plowed, snaded, cleared of frost, snow and ice pack, and widened as quickly as possible even through this involves working extra hours at night or Sundays, or legal holidays. The work is prosecuted as vigorously as practicable so that roads are maintained in as good a condition as possible with the equipment, materials, and men assigned to the work. First attention is given danger spots such as steep grades, sharp curves, intersections, bridges, bridge approaches. In territory where light snowfall is expected regular maintenance trucks equipped with displacement plows are provided. When snow removal is a routine winter operation, truck push plows either straight or "V" type blades and trucks with rotary plows are provided as well as other types of equipment necessary to remove snow. Plows with rubber bits are particulary effective in slushy snow or snow that has not been compacted by traffic and minimizes damage to raised traffic buttons. Chemicals and abrasives are spread full width in highly congested or urban areas and in danger spots where fast melting of the entire surface for full skid control is essential. In rural areas the width of the spread is confined to the middle third or less of a two-lane roadway. On low volume roads, skid control may be provided by spreading abrasives full width at intervals close enough to provide safe movement. On high priority highways, snow plowing or chemical and sand application should have begun after an accumulation of 1/2 to 1 inch and before the snow becomes packed. Shoulders are plowed in conjunction with other plowing or immediately after the storm is over, and definitely before the ground thaws out. Priority One: Continuous effort with sufficient equipment and personnel to prevent an accessive accumulation during a moderately sever storm and undue delay at any hour of the day. Snow removal operations on a priority-one class highway will proceed without interruption and continue throuigh and after the storm until the roadway is bare of snow bottom. Continued maintenance to insure ice conditions are controlled by the application of sand or chemicals. Priority Two: The need for immediate snow removal is not as critical therefore, accumulations of one to two inches of fresh snow over a compact snow bottom during a normal snow storm may be allowed. Priority Three: Less initial attention ad higher accumulation (three to four inches) of snow during a normal strom can be permitted. A well sanded compact snow bottom will be tolerated during the winter months. Under thawing conditions, slush and broken

STATE	LEVEL OF EFFORT AND/OR LEVEL OF SERVICE - Guidelines and/or Standards
WASHINGTON (Cont.)	ice is removed as soon as practicable to prevent the road from refreezing in an intolerable condition. Generally chemicals will not be needed except in areas where actue hazards occur.
WEST VIRGINIA	At the beginning of a storm, each unit of equipment must go to the route at the top of its list of first priority routes. It will then proceed to cover all the routes on this list in proper order. Plowing of roads that are to be treated with a mixture of abrasives and chemicals will start when there is approximately 2 inches of snow on the road, and will be continued until all the roads have been cleared and set back. The maximum allowable depth of snow on such a road is 2-1/2 to 3 inches. Four types of treatment or combinations thereof, are used for snow removal and ice control: (1) spreading of pure chemicals; (2) spreading of a mixture of chemicals and abrasive materials; (3) spreading of abrasive materials without chemicals; (4) plowing the snow. The type of treatment to be used on a particular road or section of road depends mainly on the priority of the road. Treatment with pure chemicals, which is commonly known as bare pavement maintenance, is possible only on certain first priority routes. Plowing and treatment with a mixture of chemicals and abrasives is applied on all other first priority routes and on some second priority routes. The third priority routes are plowed, but are not given any other treatment. Fourth priority routes are not plowed, but are allowed to be closed by snow and remain closed, except under unusual conditions. Work on the other parts of the clean-up phase will normally be done only during the daylight hours, since the work is not of an emergency nature.
WISCONSIN	Winter maintenance is provided by the counties on the state trunk highway system as required. They also provide for the supervision and direction for these activities. Bare pavements are to be provided as expeditiously as practicable on highways having high traffic volumes. The District Chief Maintenance Engineer shall determine which highways shall have priority on the basis of their critical nature. Highways with low traffic volumes shall be cleared as expeditiously as is economically and operationally practical to provide reasonable security for traffic. It is desirable on low traffic volume highways that, as soon as practicable after a storm, bare pavement of sufficient width be provided near the centerline to give traction for traffic in both directions. Completely bare pavement should, however, be provided on hills, curves, and at intersections as soon as possible. Operations begin as soon as storm, driving conditions and traffic density require and shall continue throughout the storm or for as long as prudent, considering storm intensity and vision restrictions. Chlorides shall only be applied during a snowfall as necessary, when temperatures and wind velocity indicate that satisfactory results may be expected. Chloride treated abrasives may be used as required to expedite the movement of traffic during the early stages of ice formation and shall be used when temperatures preclude the use of raw chlorides.
WYOMING	Class A (Bare Road): Ambient temperatures and the related snow type are the prime determining factors as to when snow plowing operations begin. "Wet Snow" associated with warmer temperature usually requires immediate plowing and sanding response to prevent excessive snow and ice pack. Cold "dry snowfall" depths should be allowed to buildup to 1-2 inches before plowing work begins. Once plowing begins, plows endeavor to obtain a bare road over the entire traveled way. As the storm subsides, extend plowing to truck climbing lanes and other important widening areas. "Wet snows" usually require immediate treatment during plowing, enabling the development of a brine on the pavement. Immediate application of abrasive and chemical when plowing "cold snow" is usually not warranted. Crews should be organized by staggering or rotating shifts to allow plowing work to continue through all hours. It is intended that plowing will not generally be performed between midnight and 4 or 5 a.m. Overtime policy guidelines observed during all work. At the end of the storm, provide Class D service. Class B (Open Road): As in Class A, initial plowing response is dependent on type of snow. In "dry snowfall" 2 inch depths before plowing, "wet snowfall" requires a quicker initial plowing and sanding response.

STATE	LEVEL OF EFFORT AND/OR LEVEL OF SERVICE - Guidelines and/or Standards
WYOMING (Cont)	After plowing is started, the major effort is keeping the road open with less emphasis on keeping it bare. (Not to preclude removing loose snow before becoming snow or ice pack). Abrasive treatment and chemical application follows that outlined in Class A, except on sections of straight road (on tangent) unless considered hazardous are not treated. Work schedule should be such that plowing is done generally between 5:00 a.m. to 10:00 p.m. Class C (Reduced Speed Road): Plowing is usually not commenced until men and equipment are released from Class A and B roads. An exception to this is the opening of a road for school bus or similar type traffic. In meeting this criteria, snowfall depths of 3 inches may be accumulated before plowing, and abrasives are applied. Work schedule should be such that plowing is done during daylight hours only. At end of storm provide Class D Service. Class D (Cleanup): Cleanup operations are not to be performed until all roads in the area have been provided with their designated class of service. Work is to be performed during normal working hours. Work generally consists of removal of snow ridges at the shoulders, widening areas for future snow storage, cleaning of minor interchanges and smoothing out snow ridges at approaches. Class E (Seasonally Closed Road): Close road when snow depth requires; Open as soon as feasible in Spring.

SODIUM CHLORIDE SPECIFICATIONS FOR UTAH DEPARTMENT OF HIGHWAYS

1972 - 1973

SODIUM CHLORIDE UNTREATED (TYPE "A")

Sodium Chloride for use as a highway deicing agent shall not be less than 92% (NaCl). The percent of Sodium Chloride (NaCl) shall be determined in accordance with ASTM Designation D-1411.

All Sodium Chloride shall meet the following gradation requirements:

TABLE 32: SALT GRADATION IN UTAH

SIEVE SIZE		PERCENT PASSING
METRIC	STANDARD	
12.5 mm	1/2 inch	100
9.5 mm	3/8 inch	90-100
4.75 mm	No. 4	50-80
2.36 mm	No. 8	10-60
1.18 mm	No. 16	0-35
.150 mm	No. 50	0-3

SODIUM CHLORIDE NON-CAKING (TYPE "B")

Yellow Prussiate of Soda (YPS) or other approved chemical shall be uniformly added to the Sodium Chloride at a ratio of not less than 200 parts per million (200 PPM) to produce a non-caking material when subjected to the following test:

The materials shall be exposed to two (2) twenty-four hour moisture cycles from 3% minus moisture by weight to 25% plus moisture and back to 3% moisture.

The addition of the Yellow Prussiate (YPS) to the Sodium Chloride shall be done prior to stockpiling and shall be done in such a manner as to produce a uniform coating throughout all crystals.

SODIUM CHLORIDE WITH NON-CAKING AND ANTI-FREEZE AGENT ADDED (TYPE "C")

Sodium Chloride furnished under Type "C" shall be treated with Yellow Prussiate of Soda (YPS) as specified in Type "B". In addition, Magnesium Chloride Hexahydrate ($MGCL2 \cdot 6H20$) or other approved chemical shall be uniformly added to the Sodium Chloride at not less than one-half of one percent by weight of the total sample. The Magnesium Chloride Hexahydrate ($MGCL2 \cdot 6H20$) or other approved chemical shall be added in such proportions as to allow solubility of water (H_2O) within the temperature range of -18°C to 0°C (0° to 32°F). The solubility rate of the added chemical shall be from instant to 30 minute time laps. The addition of the Magnesium Chloride Hexahydrate ($MGCL2 \cdot 6H20$) or other approved chemical shall be introduced prior to stockpiling and in such a manner as to get uniform coating of all crystals.

SELECTED PRACTICES OF SELECTED STATES IN COMBATING SNOW AND ICE

Minnesota

1. Regular complement is based on manpower needed to operate the required number of trucks, for the standard coverage time. Total manpower should conform to the following criteria.

Urban Commuter	2-1/2 men per truck
Rural Commuter	2 men per truck
Primary	2 men per truck
Secondary	1 or 2 per truck

One man for twelve hour or one man for six hour shifts may be used on secondary routes. Only highway and landscape maintenance workers (including senior) are to be included in this complement. It is not required that project maintenance foremen (intermittent) be considered as part of the complement in those sub areas which have urban commuter routes.

2. Auxiliary complement required for snow removal support operations includes heavy equipment operators, bridge workers, highway maintenance worker-signs and highway maintenance worker, senior signs. No recommendation has been made as to the criteria for determining this complement of specialists.

3. Highway technicians should be used as replacement personnel and as second men when needed.

Massachusetts

Snow and Ice Control is a major traffic service and it is also considered an emergency operation. Any operation which is so classified requries extensive preparation to be successful. Personnel must be organized and trained for their assigned tasks. Equipment must be available and in condition to operate on short notice. Materials must be stockpiled, and balances under contract so that they will be available when needed. The regular maintenance organization is augmented during the snow season by emergency employees who are employed.

During a storm every effort shall be made to utilize all available mechanical equipment for snow and ice control. Based on the available manpower, it will be necessary to use one-man truck operation whenever weather and road conditions permit a safe operation. Two-man operations may be used when more than one operation is being carried on at the same time.

One-Man Vehicle Operation -- One-man operation will be used under the following conditions:

1. Whenever weather and road conditions permit a safe operation.

2. Single operations such as sanding or chemical application.

3. Snowfall does not produce large windrows on traveled surface.

4. Foreman must be willing and able to perform the one-man operation.

Two-Man Vehicle Operation -- Two-man operation may be used when any of the following conditions exist:

1. Poor visibility due to blowing snow which may affect a safe operation.

2. 2. Snowfalls that produce large windrows that require more than one operation to move off the traveled portion of raodway.

3. Certain hazardous roadways with extensive left turn slots.

4. Winging operations will require a two-man operation.

5. Any other condition which is considered not safe for a one-man operator.

Combination of One-Man and Two-Man Operations -- The combination of one-man and two-man vehicle operations should be used when safe and traffic movements have normalized, thereby allowing less restriction in use of manpower and equipment. The work that is usually performed under this arrangement is as follows:

1. Removal of snow from shoulders and adjacent slopes to provide additional space for next storm.

2. Removal of snow from intersections and other locations where high banks interfer with sight distances.

3. Resumption of normal maintenance operations.

4. Perform any operation that will return traffic movements back to normal.

The present staffing in most sub-area will permit two 12 hour shifts under severe weather conditions. However, in several sub-areas only one shift will be possible, consequently some trucks may be idle during the second twelve hour period. No night shifts are purposely scheduled in the District, except for the off hour patrol.

Under ordinary work days, when snow and ice removal is not a pressing factor in the movement of traffic, all crews that are not off duty on compensatory overtime will work the regularly scheduled hours from 8:00 a.m. to 4:30 p.m. Monday through Friday. In the event of a snow storm or predicted storm, a portion of the crew is sent home early to prepare for a second shift, if needed. The first shift would remain on duty four additional hours (to 8:00 p.m.) and be relieved by the second shift at that time. The second shift would work for a maximum of twelve hours and be relieved by the day crew at 8:00 a.m.

In the event of a snow storm beginning after about 4:00 a.m., and no night crews are on duty (except for the night patrol), the night crew would not be called out at that hour, but the day crew whould then be called out early. The crew change would necessarily be made at 4:00 p.m. rather than at 8:00 p.m.

As in the past, night crews will patrol the entire Maintenance Area to assure that prompt action will be taken as needed in the event that icing, slippery spots or snow accumulations are developing on our highways and bridges. This service is designed to operate seven days per week, 24 hours per day, except between the hours of 8:00 A.M. and 4:00 P.M. on Saturdays and Sundays. Two night patrols will be based at Maplewood, and one each at Forest Lake, Arden Hills, Oakdale, St. Paul Park and Farmington.

No crew on duty will be permitted to take coffee breaks or meals between the hours of 5:00 A.M. and 8:00 A.M., and between 5:00 P.M. and 7:00 P.M. This is to avoid criticism by rush hour traffic motorists of the Maintenance crews not "doing everything possible" during these critical hours.

Act Number Thirty one of the General Laws, and all amendments thereto, read in part:

> *1) Laborers-employed between October thirty-first and April fifteenth to be used in connection with the removal of snow and the sanding of slippery surfaces with the incidental work thereto on the highways of the Commonwealth, such employment in each case not to exceed a total of ninety days within that period, and such employees when available and able to perform the work satisfactorily; (2) such temporary employees as required during the following a disaster or period of extreme danger when and as authorized by the Governor, but not to exceed ninety days.*
>
> *Preference shall be given to veterans in making appointments and employing persons under the provisions of clauses (1) and (2) of this paragraph.*

1. Removal of snow from shoulders and adjacent slopes to provide additional space for next storm.

2. Removal of snow from intersections and other locations where high banks interfere with sight distances.

3. Resumption of normal maintenance operations.

4. Perform any operation that will return traffic movements back to normal.

The present staffing in most sub-areas will permit two - twelve hour shifts under severe weather conditions. However, in several sub-areas only one shift will be possible, consequently some trucks may be idle during the second twelve hour period. No night shifts are purposely scheduled in the District, except for the off hour patrol.

Under ordinary work days, when snow and ice removal is not a pressing factor in the movement of traffic, all crews that are not off duty on compensatory overtime will work the regularly scheduled hours from 8:00 A.M. to 4:30 P.M. Monday through Friday. In the event of a snow storm or predicted storm, a portion of the crew is sent home early to prepare for a second shift, if needed. The first shift would remain on duty 4 additional hours (to 8:00 p.m.) and be relieved by the second shift at that time. The second shift would work for a maximum of 12 hours and be relieved by the day crew at 8:00 a.m.

In the event of a snow storm beginning after about 4:00 a.m., and no night crews are on duty (except for the night patrol), the night crew would not be called out at that hour, but the day crew would then be called out early. The crew change would necessarily be made at 4:00 p.m. rather than at 8:00 p.m.

The use of secondary classifications on Snow and Ice Control operations must be kept under close control within the Districts. Secondary ratings shall be used only for the length of time the employee is actually engaged in the work covered by such classification, and only when absolutely necessary. Permanent employees who are qualified to do the work required for secondary classification shall be given preference over temporary employees.

A complete list of names, addresses and telephone numbers of all District Maintenance Engineers and Assistant Maintenance Engineers, Highway Maintenance Foremen and Highway Repair Foremen shall be submitted by each District to the Maintenance Engineer in Boston early in September so that a statewide directory of the Emergency Organization for winter storms and other natural disasters can be prepared. The list shall also include the telephone numbers of all storehouses, section garages, field offices and all other maintenance installations which are used as bases for Snow and Ice Control Operations.

North Dakota

Organization of personnel for winter maintenance operations requires considerable thought and good judgment by the District Maintenance Engineer and the Maintenance Superintendent. Assignment of operations should be made in advance of actual operations.

Whenever possible assign each operator to a specific piece of equipment. Man and machine make a better team when they work together consistently. The feeling that a vehicle "belongs" to him also will make an operator show more responsibility for its upkeep.

During severe and prolonged storms, plans for staggering crews will be necessary. The storm intensity and length will alter any standard procedure and hourly work schedule. Planning for exchange of crews and rest periods will result in the maximum use of equipment and minimize crew fatique. Distribution of overtime hours should be as fair as possible and should take into consideration the employee's age, health and other factors.

It will be necessary to provide early morning sanding operations for frost conditions and ice and snow removal in addition to regular maintenance operations.

Usually maintenance employees begin work at 7:00 a.m.

Certain employees as directed by the District Engineers will be required to report at a time earlier than the above hours. Employees so directed will have hours established for no earlier than 5:00 a.m. Districts may establish a later time after 5:00 a.m. depending on particular circumstance. Such hours, if established, must be on a regular weekly scheduled basis.

The total number of employees as well as specific employees involved will be determined by each District under guidelines as established by each District under guidelines as established by the Maintenance Engineer's Office. As stated previously, schedules should be developed by Districts and posted weekly on a rotating basis.

In addition, certain employees as designated by each District will be required to report for work no earlier than 5:00 a.m. on Saturday and Sunday. Districts may establish a later reporting time depending on particular circumstance.

Employees who report on these days will be paid at least two hours cash overtime each day. If conditions require, they can be retained for additional hours with cash overtime for the hours worked. No added compensation will be made for early show-up. A rotating schedule should be posted for all Saturday and Sunday work for equal distribution among employees.

It may be necessary during long periods of continual snow removal operations to make arrangements for operations of the shops on a shift basis. One mechanic and someone to help should be available at all times. One mechanic should be assigned to the shop truck for making minor repairs to equipment on the road.

Iowa

During the winter there is usually one or more occasions when some part of the state is hit by an unusually heavy snow storm while some other part of the state has no snow or very light snow. Long or heavy snow storms require many hours or days of work to clear the roadway. The challenge and devotion to duty is so great that operators work long hours without sufficient rest. This is not only hard on the operators but tired operators are more subject to an accident that may cause injury to themselves and the traveling public. Local extra help is sometimes not available for relief and seldom sufficiently trained to drive snow plow equipment. Therefore, when possible, operators from outside the storm area will be sent in to help so the work can proceed while some operators sleep and rest. The groups of men sent to help will be called Relief Snow Plow Crews.

A Relief Snow Plow Crew will consist of three operators with one pickup for transportation. One of the three operators shall be experienced in the operation of a truck equipped with wing and underbody blade and other operators shall be experienced in driving a two ton snow plow truck. One or more relief crews of three men each will be moved into an area to help with the snow work if requested and if available.

During such emergencies an employee shall work no more than twelve continuous hours, including breaks for meals and servicing, except that sixteen hours maximum is authorized for the first day of a storm. After working this number of hours the employee shall have at least eight hours rest before returning to work.

Kentucky

During the time period from December 15th to March 1st the District Office and the Crew Foremen should implement a plan that would place at least one man (preferably two) at the maintenance site during the night. This would not or need not be overtime basis. These men would work their regular shift from 9:00 p.m. to 5:00 a.m. Their presence should allow for night time delivery of salt, for preparing equipment for the next day's operation by greasing, fueling and cleaning and keeping track of the weather conditions as they develop. During any storm the Foreman should not permit any men on the crew to work longer than sixteen hours continuously. After a sixteen hour shift the employee should rest for eight hours before resuming duties.

This will require that the Foreman keep some key personnel in reserve at all times. In many cases, employees will be sent home during the normal working hours in order to implement a relief system.

The County Foreman should make contact with local police, toll collectors or other responsible persons who are working at night so that they can give him warnings of developing snow and ice conditions. The County Foreman will maintain a careful inventory of his salt, chloride and abrasive stockpiles. He shall report each salt delivery and each day's salt usage to the District Office.

The County Foreman shall keep a Storm Log for each storm. The Storm Log will be filled out in its entirety and retained for two years in the District Office. With the new Sub-ledger Code reporting system allowing snow and ice removal to be charged to county general, District personnel must insist on accuracy of the Storm Log, as this record will be the only written documentation for use in answer to compliants and as evidence in law suits. The Storm Log should also be used to check salt spreader calibrations.

Virginia

In snow removal operations the number of people needed depends on the number of trucks and other equipment needed to maintain continuous plowing operations with adequate frequency of coverage and how they are assigned.

After the equipment needs have been determined by laying out a plowing plan, the number of people required can be determined by considering the following:

- Any truck operating alone should have someone riding "Shotgun" except under unusual circumstances.
- At least one truck of two or more plowing as a team in echelon should have a "shotgun" rider.
- When only one man per truck is avilable due to illness, extended emergency conditions, inability of some to report for duty, or other reasons, assignments may be adjusted so that as few trucks as possible operate completely alone. They should either be placed in a two truck team, or in some way given occasional support by another truck or motorgrader.

Using these rules as a basis, along with some common sense, the following will tell the number of people needed in an area for snow removal in addition to the timekeeper and superintendent.

- One qualified operator for each truck or motorgrader needed for use in snow removal for each shift.

> (Example, if five trucks and one motorgrader are found to be needed - this would mean six operators on each of two shifts or twelve operators.)
> (One foreman should take supervisory shift to provide rest for the Superintendent.)

- One additional person to ride "shotgun" in each truck that is assigned either to work alone, or has been designated as likely to be moved to another road.

- Usually not more than two other permanent maintenance employees as a reserve to replace those who may be ill when the emergency occurs or unable to report for other reasons.

In areas needing five truck and one motorgrader to maintain adequate continuous plowing (as determined from planning) and in which one truck is assigned to work alone and two others are designated as subject to change of assignment (Motorgraders given such assignments still only need one man per shift) would need:

	5 trucks	x 2 shifts	=	10 operators
	1 motorgrader	x 2 shifts	=	2 operators
and for	1 truck alone (rider)	x 2 shifts	=	2 riders
and for	2 trucks (riders)	x 2 shifts	=	4 riders
Subject to assignment change		plus	=	2 extra
				20 people

This does not mean that if a greater number of people are needed for other major activities through the rest of the year that there should not be more than twenty. It also does not mean that inspectors should not be used to provide a rider in those trucks that do not have them. The number twenty is simply the number that can accomplish the work safely and consistently under all but very unusual conditions.

Pennsylvania

MATERIAL PREPARATION

Normal seasonal requirements for sodium chloride (salt), calcium chloride and anti-skid materials should be determined and depending upon capacity the arrangements made for delivery and storage of 1/3 of the estimated seasonal requirements in advance of the winter season. Adequate storage capacity should be provided to reduce the possibility of a shortage during storm periods and facilitate speed and ease of handling.

CHEMICAL STORAGE

BULK STORAGE

To reduce loss due to caking and runoff of salt and calcium chloride, properly constructed storage facilities must be provided and the following basic storage requirements will be followed.

(1) Bulk chlorides will be used because of their lower cost and ease of handling.

(2) Keep chemicals dry during delivery.

(3) Keep chemicals dry during storage. (Use only waterproof tarps. During loading the cover will be rolled back only far enough to allow the loader to get the necessary amount of material and will be replaced as soon as loading is complete. Chemicals will never be left uncovered after loading is completed). Covers should be held in place with an old tire or sand bags. Grader blades, fence posts or other articles with sharp edges that may damage covers should not be used.

(4) Store chemicals on well drained paved areas.

(5) Sodium chloride can be stored either in covered buildings or outdoors under proper cover.

(6) Calcium chloride is more sensitive to moisture than sodium chloride. It must be protected from precipitation, ground water and the free movement of moist air over and around it. Therefore, it must be covered at all times. Storage in treated wood buildings is preferred for calcium chloride, but it can be stored successfully under cover outdoors.

(7) Store calcium chloride salt mixtures as you would store calcium chloride.

(8) Use only dry salt for mixing with calcium chloride.

(9) When feasible, chemicals remaining in storage at the end of the winter, shall be moved into dome shaped storage facilities. When this is not possible chemicals shall be carefully covered for the summer months.

(10) Pad with Crib - If a crib is erected on an existing pad the capacity of the pad is increased by over 50 percent. One side of the crib should be left open to give loading equipment access to the material. Material that has been stored the longest should be used first. Cribs should be built low enough so that one man can remove and replace covers. Use the same type of cover recommended for pad storage. The cover should be tied to the sides of the crib and held down on the open side by tires or sand bags to keep air from getting under the cover.

(11) Bay Buildings - Sodium chloride may be stored in these structures without a waterproof cover. However, a waterproof tarp must be placed over calcium chloride or calcium chloride salt mixtures and the edges tightly held down so that air cannot get in.

DOMED STORAGE FACILITIES FOR SALT

In some Districts high capacity dome shaped salt storage facilities have been erected. Loaded properly these buildings will store 1800 tons of salt. Proper loading procedures are outlined below:

Both a tri-axle and a ten wheeler vehicle are suitable for loading of the dome structure. The tri-axle is preferable because of its larger pay load (23 Ton vs 17 Ton [21 vs 15 metric ton]). A tractor trailer is not desirable as its length reduces maneuverability inside the dome structure.

A. Vehicle drives into structure as indicated by arrow, backs to lined area, dumps several loads.

B. Darkened area is now loaded with salt. Vehicle drives into structure as indicated by arrow, backs to lined area, dump several loads.

C. Vehicle backs into structure as indicated by arrow, dumps several loads.

While the loading process is going on a front end loader should be shaping the salt as required. Following this method of storage with the recommended vehicles approximately 1000 tons (900 metric tons) of salt should be dumped inside the building. From that point onward the salt will have to be dumped outside the building and brought in with a front end loader. It is recommended that a front loader with 2 1/2 yard (1.9 cubic meter) bucket be assigned to this operation. This loader is capable of moving 75 tons (68 metric tons) an hour into the Dome Building.

When 0 to 500 (450 metric) tons of material are in the building cycle time (time truck enters yard full until it leaves empty) is four minutes. Between 500 and 1000 (450 and 900 metric) tons cycle time increases to eight to twelve minutes, over 1000 (900 metric) tons, cycle time is approximately twenty minutes.

BAG STORAGE

Bags should be protected from direct rain and snow. Storage should be in a dry, well ventilated room or building with a wood or concrete floor. The bags should be piled and stacked alternately on planks of timber raised about 4 inches (10 centimeters) above the floor to permit air to circulate below the bottom tier. Ordinarily, older bags should be used first. If however, a bag becomes broken it should be used ahead of others. If bags must be stored outdoors, the bottom tier should be laid on raised planks and the pile protected by a waterproof covering. During summer months bags and chemicals in small stocking area should be moved to Domed Buildings.

SAFETY PRECAUTIONS

Contact of chemicals with the eye is likely to produce sufficient injury to result in loss of time from work. Single prolonged exposure to the skin may result in some reddening, while repeated prolonged contacts may cause appreciable irritation and possibly a mild burn.

Reasonable handling, care and cleanliness, plus the use of safety goggles should be sufficient to prevent injurious contact. Where gross skin contamination with solids or solutions does occur, the affected area should be washed thoroughly with clean water and medical attention obtained. Contaminated eyes should be washed thoroughly with large quantities of flowing water and a physician summoned.

MIXING CHEMICALS

For storms with temperatures under 25 Degrees Fahrenheit (4°C), a mixture of sodium chloride (salt) and calcium chloride is sometimes used. The decision to use such a mixture depends not only on the temperature but also on the type of precipitation and road condition.

Mixing should be accomplished by mechanical means. Desired proportions of sodium or calcium chloride are placed into a pile and rehandled with the equipment until a uniform mixture is obtained. The material is handled a second time when loaded into the spreader, which furthers the mixing.

Another method of mixing is to load alternate layers of salt and calcium into the truck bed in proper proportions at the time of use. This method is acceptable where the spreader is one of the smaller types and bags of chemicals are used. However, a thorough mixing of chemicals is not obtained resulting in an uneven distribution of materials on the road. Loading time is also slowed down because the loader must load from two different piles.

If past history shows a continuing need for a salt-calcium mixture, mixing can be eliminated by ordering pre-mixed salt and calcium from the manufacturer. The ratio of this pre-mixed material is five parts salt to one part calcium.

ANTI-SKID STORAGE AND TREATMENT

Freezing of the moisture within anti-skid material must be prevented in order to keep the material free flowing through our mechanical spreaders. The following methods of anti-skid treatment are recommended.

1. No internal treatment. The outside surface of the anti-skid pile may be capped with a thin layer of bag calcium chloride. (2 lbs. per sq. yard [1 kilogram per square meter]).

2. Treating the anti-skid pile with salt on a volumetric anti-skid to salt ratio of 10:1. A 10 to 1 mix will provide ample salt to keep the pile from freezing.

3. Treating the anti-skid pile with salt on a volumetric anti-skid to salt ratio of 7:1. A 7 to 1 mix will provide sufficient salt to cause some melting action when temperatures are 30 Degrees Fahrenheit (-1°C) and rising.

4. Mixing Type I calcium chloride with anti-skid at the rate of 60-80 pounds (30-35 kilograms) of Type I Calcium or 50-70 pounds (20-30 kilograms) of Type II Calcium per ton of anti-skid.

Care must be exercised to prevent chemically treated anti-skid from leeching into water supplies.

MATERIAL APPLICATION RATES

On First Priority Routes, MFC A & B, Department policy is to spread 100% chemicals. Spreading width shall not exceed twelve feet (3.7 meters) on these highways.

On Second and Third Priority Routes salt abrasives, or a combination thereof is spread in accordance with the GUIDELINES FOR APPLICATION RATES TABLE. When spreading salt on two lane roads twenty feet (6 meters) or less in width, the salt shall be spread at a width of four to six feet (1 to 2 meters). If the roadway is superelevated, the salt shall be spread toward the high side of the road.

When spreading abrasives or salt mixed with abrasives, the spreading width must never exceed the pavement width.

West Virginia

STORAGE PILE LOCATIONS

The County Superintendent, with the aid of the District Maintenance Engineer, must determine where chemicals and abrasives for snow removal and ice control operations should be stored. The storage places will be located so the spreading equipment will not be required to travel a great distance while empty to reload or a great distance while fully loaded to reach the starting point of the spreading operation.

Furthermore, the storage place will be well drained and easily accessible. Stockpiles will also be located at all sites where snow-removal equipment is parked. This practice will expedite loading so that loaded equipment can be on the road as soon as possible.

CHEMICAL STORAGE

Chemicals and abrasives must be stored in an approved manner to reduce loss due to caking and water damage. The bin may have two or three sides. It must be set on a hot-mix pad which is so constructed that water will drain from the center to the outer edge in all directions. Eye bolts placed 12-24 inches (30-60 centimeters) apart must be located in the sides at the top for use as ties to hold a waterproof cover in position. The cover will be placed so that it will be in direct contact with the chemical. It must be securely tied on two or three sides and will be held on the pad at the front or at each of the open ends. Bins will be arranged in sets of three. The two outer bins of a set will contain the straight chemicals. Rock salt will be stored in one, and calcium chloride in the other. The center bin will contain the standard mixture of salt and calcium chloride that is best suited for the particular County. Care must be taken to keep all chemicals covered except during actual loading operations. During loading, the cover will be rolled back only far enough to allow the loader to get the necessary amount of material and it will be replaced as soon as loading is completed. Chemicals will never be left uncovered after loading is completed.

ABRASIVE STORAGE

Abrasives will be stored in stockpiles on well-drained ground. At each location there will be two stockpiles, one of straight abrasives and one of abrasives mixed with chemicals. Each stockpile must be built and maintained in the shape of a cone. A pile of this shape tends to shed water readily. As a result, there is less chance of deep freezing in a pile of straight abrasives and less chance of loss of chemical due to leaching. A stockpile of abrasives mixed with a chemical will be capped with an application of straight chemical to compensate for the loss of chemical through leaching. Also, where practical, a waterproof cap must be kept in place on a pile of abrasives even though the pile includes chemicals. After each storm, stockpiles of abrasives must be reconstructed so as to have the proper shape. Each pile must then be recapped with a chemical or the waterproof cap replaced.

STORAGE SITE INSPECTION

All chemicals and abrasives for snow removal and ice control must meet the requirements of the specifications prepared by the West Virginia Department of Highways. The material will be inspected in accordance with the established policy. Only material that meets these specifications will be accepted.

MIXING CHEMICALS

Chemicals are used straight and in combination. The choice of type and mix depends on the temperature and on the road conditions. A standard mixture will be determined for each County on the basis of the average temperature and the type and amount of precipitation. Experience will be of tremendous help in determining the correct or best standard mixture. A number of methods can be used to prepare a satisfactory mixture. It will be assumed that a mixture of rock salt and concentrated calcium chloride in pellet or granular form is to be prepared.

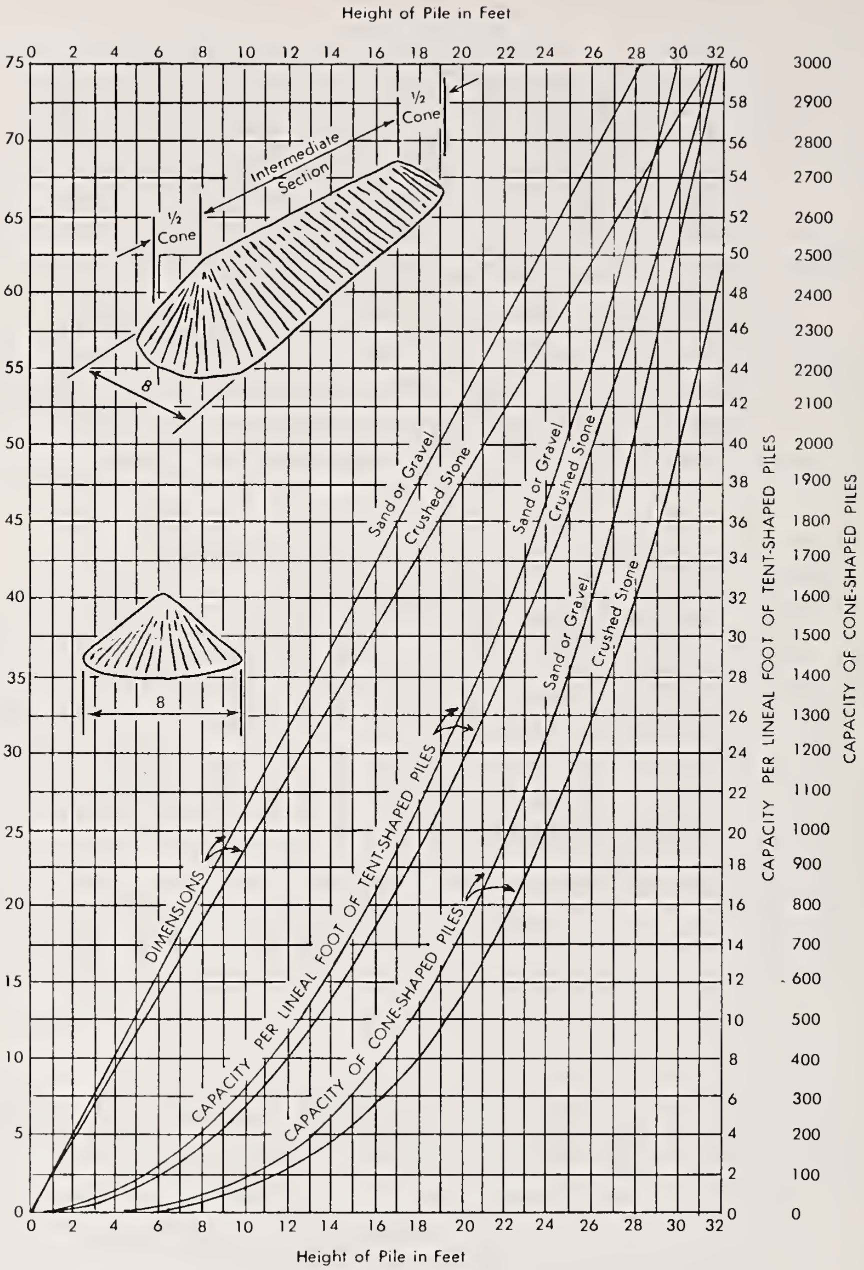
Mixing can be done with the use of a front-end loader, a power shovel, a clamshell, or by hand-tools. Suitable amounts of salt and calcium chloride are placed into a pile in the desired proportions and the actual mixing is accomplished by rehandling the material with the equipment until a uniform mixture is obtained. Another method of mixing is by the use of equipment of the belt-loader type with a hopper feeder. The salt and the calcium chloride are put in separate piles. Then the loader is backed into the pile of chemical of which the larger amount is required. The other chemical is added through the hopper in as even a flow as possible and in the correct amount.

In another method ofmixing, alternate layers of salt and calcium are placed in the hopper or body of a spreader in proper proportions at the time of use. This method is accepted where the speader is one of the smaller types and bagged chemicals are used. It permits only limited mixing by the normal movement of the materials through the body to the discharge opening.

MIXING CHEMICALS AND ABRASIVES IN STOCKPILES

It must be remembered that chemicals will not prevent the freezing of moisture in abrasvies and will not allow abrasives to become quickly anchored to ice or packed snow unless the chemical has been dissolved and become uniformly mixed with the abrasives. For this reason, 100 pounds (45.4 kilograms) of chemical will be added to each cubic yard of abrasives and thoroughly mixed when the abrasives are stored in stockpiles. This initial addition of chemical will keep to a minimum the need for "sweetening" (adding addtional chemical) the abrasives at the time of spreading. Before the snow seasons, ample quantities of abrasives should be on hand and enough chemical should be available for mixing100 pounds (45.4 kilograms) with each cubic yard of abrasvies. The chemical added to a stockpile of abrasives should be mixed with the abrasives in the following manner:

Step 1. The number of cubic yards of straight abrasives delivered to the stockpile will be determined either from the delivery weight slips or from the base dimension of the pile by the use of the Storage Capacity Curves shown on the chart in Figure 83. To us this chart, it is first necessary to determine the height of the pile corresponding to the base dimension "B" by considering the proper sloping straight line. For example, a pile of crushed stone with a base dimension of 40 feet (12.2 meters) should have a height of seventeen feet (5.2 meters). The capcaity of a conical pile or the capacity per lineal foot of the intermediate section of a tent-shaped pile should then be found for the known height by considering the proper curve. Thus, a conical pile of crushed stone seventeen feet (5.2 meters) high should contain about 360 tons (327 metric tons) and each lineal foot of the intermediate section of a tent-shaped pile should contain about 17.5 tons (15.9 metric tons). To find the total capacity of a tent-shaped pile, the capacity per lineal foot must be multiplied by the length of the



Curves based on:
Unit weight of aggregate of 100 pounds per cubic foot.
Angle of repose of sand and gravel of 37°
Angle of repose of crushed stone of 40

FIGURE 86: STORAGE CAPACITY CURVES

intermediate section and the capacity of a conical pile of the same height must be added to allow for the sloping end portions. Thus, if the intermediate section of the tent-shaped pile as mentioned above is 50 feet (15.2 meters) long, the total capacity of the pile will be (17.5 x 50) + 360 = 1235 tons (1120 metric tons).

Step 2. By use of a clamshell or a power shovel, a new stockpile will be built by placing alternate layers of the abrasives from the original stockpile and chemicals in the correct proportions. To accomplish this, each layer of abrasives will be approximately two feet (50 centimeters) in depth and the number of cubic yards in the layer will be determined by counting the number of bucketfuls needed to construct the layer. The corresponding amount of chemicals required can then be determined for each layer and will be spread as evenly as possible over the entire surface of the layer of abrasives. This procedure will be combined until all materials have been proportioned.

Step 3. The equipment will be used to move the pile of combined abrasives and chemical to an adjacent place by letting the material sift gradually from the opened bucket.

Step 4. The final mixing will be performed while the material is being moved to its permanent location by gradually opening the bucket of the equipment and letting the material sift through as before.

Step 5. The mixed material will be deposited so as to form a pile of the proper shape. This pile will then be capped with a thin layer of straight calcium chloride. A waterproof covering can be used as a cap instead of the chemical to aid in shedding water. The cap, whether of waterproof material or of calcium, should cover the pile about one-third of the distance from the top.

PROPORTIONS FOR CHEMICAL MIXTURES

The best proportions of rock salt and calcium chloride in a mixture of chemicals depend on the temperature. When pellets of concentrated calcium chloride are used, the standard mixtures by volume recommended for various temperature ranges are as follows:

Temperature	Proportions by Volume
-2.2°C(28°F) or higher	Straight salt
Between -2.2°C(28°F) and -5.5°C (22°F)	1 part calcium chloride to 3 parts salt
Between -5.5°C(22°F) and -8.9°C (16°F)	1 part calcium chloride to 2 parts salt
Between -8.9°C(16°F) and -12.2°C (10°F)	1 part calcium chloride to 1 part salt
Between -12.2°C(10°F) and -15.5°C (4°F)	2 parts calcium chloride to 1 part salt
-15.5°C(4°F) or lower	Straight calcium chloride

By using these recommendations as a guide and basing the proportions on the average temperature during snowstorms, the best standard mixture will be determined for each County.

SPREADING CHEMICALS

As soon as precipitation in the form of snow, sleet, or freezing rain starts, application of the correct mixture of chemicals will begin. The initial application of the chemicals is very critical, because the promptness of the application and the amount of chemicals applied determine if the precipitation will stick to the pavement.

Under certain conditions it is advisable to apply chemicals before precipitation occurs. For example, when heavy storms are known to be advancing on a wide front through the state and the time of arrival at any location can be predicted rather accurately. On high-speed roads some chemical placed ahead of the storm will be "fanned-off" by vehicles, but it is better to take this loss than to wait and start application after such storms arrive.

The rate which chemicals will be applied will be determined by an authorized person before each coverage is started. As a guide in selecting the correct rate, use of the following quantities is recommended.

	Rate Based on Two Lanes	
	Pounds/mile	Kilograms/kilometer
Light snow, sleet or freezing rain	500	140
Normal snowfall	800	230
Very heavy snowfall, packed snow or ice	1000	280

If concentrated chemical is used, the pounds per mile may be reduced approximately twenty percent. The chemicals will be spread over a width of four to six (1 to 2 meters) along the center of the roadway. On a superelevated curve, when traffic and road conditions permit, the chemicals will be spread on the high side of the roadway. The spreader truck will be operated at a speed which is consistent with the results of the tests made for calibrating the spreader. However, this speed will never exceed 25 miles per hour (40 kilometers per hour), because a higher speed tends to destroy the desired pattern of spread.

PLOWING AND SPREADING ABRASIVES

Where bare surface maintenance is required, the depth of the accumulation of snow on the road will never be permitted to exceed three inches (7.6 centimeters). When the depth reaches two or three inches (5 to 8 centimeters), with snow still falling, the snow will be plowed to the surface of the pavement and the pavement will be covered immediately with another application of chemicals.

There will be times when abrasives will be needed on sections of roadway being given bare pavement maintenance. In these places, straight abrasives can be used but they must be put on quickly. When the snow has stopped, all slush will be plowed promptly from the surface of the pavement so the pavement may dry quickly and refreezing of the slush on the road surface will be prevented.

TREATMENT PROCEDURES

A great many variations in conditions can and will occur during snowstorms. The best procedures for applying chemicals, plowing, and spreading abrasives for particular conditions must be determined to some extent by experience, but the following procedures should be used as guides. Procedures for three different kinds of conditions are described as follows:

CONDITION I

Temperature: -2°C (28°F) or above and rising

Precipitation: Snow, sleet, or freezing rain

Pavement: Wet

Immediate treatment:

Salt will be applied at the rate of 500 pounds per mile (140 kilograms per kilometer).

Following treatment:

If precipitation continues and snow or sleet accumulates, the road will be plowed and salting will be repeated at proper intervals of time.

If the storm ceases, patrolling operations will be maintained until the pavement is clear. Then equipment will be shifted to second and third priority snow routes.

CONDITION II

Temperature: -2°C (28°F) and falling

Precipitation: Snow, sleet or freezing rain

Pavement: Wet or slippery

Immediate treatment:

A mixture of salt and calcium chloride in the proportions recommended for the existing temperatures will be applied at the rate of 800 pounds per mile (230 kilograms per kilometer).

Following treatment:

If precipitation continues and snow or sleet accumulates, the road will be plowed and application of chemicals will be repeated at proper intervals of time.

If the storm ceases, maintain patrol until assured that pavement is clear and shift equipment to second and third priority snow routes.

CONDITION III

Temperature: Below -2°C (28°F)

Precipitation: Snow, sleet or freezing rain

Pavement: Accumulation of packed snow or ice

Immediate treatment:

A mixture of salt and calcium chloride in the proportions recommended for the existing temperature will be applied at the rate of 1,000 pounds per mile (280 kilograms per kilometer). Also, where indicated, straight abrasives will be applied immediately afterward at the rate of two cubic yards per mile (1 cubic meter per kilometer).

Following treatment:

At the first sign of loosening or melting of snow or ice, the precipitation will be bladed from the pavement. Then the application of chemicals will be repeated immediately. Also, the application of abrasives will be repeated where necessary. The treatment and patrolling will be continued until the pavement is clear. Equipment will then be shifted to second and third priority snow routes.

TABLE 33: SALT TOLERANCES OF TREES AND SHRUBS

LATIN NAME	COMMON NAME	Na Cl			COMMENTS
		Spray	Soil	General	
Abies balsamea	Balsam Fir		MT	VS	KEY: VS = Very Sensitive S = Sensitive MT = Moderately Tolerant T = Tolerant VT = Very Tolerant
Acacia			MT	VS	
Acanthopanax sieboldianus	Five Leaf Aralia			VS	
Acer species	Maple			VS, S	
Acer campestre	Hedge Maple	VT, MT		MT, T	
Acer carpenifolia	Hornbeam Maple	S			
Acerdavidii	David Maple	S			
Acer ginnala	Amur Maple	VS			
Acer grosseri v. hersii	Grassers Maple	S			
Acer Mono	Mono Maple	T			
Acer Monspessulanum	Montpelier Maple	S			
Acer negundo	Box Elder	MT, VS	MT	MT, MT	
Acer palmatum	Japanese Maple	VS			
Acer platanoides	Norway Maple	VT,T,T	MT	MT, T	
Acer pseudoplatanus	Sycamore Maple	T	VS	VS,S,VS	
Acer rubrum	Red Maple	MT	VS	VS	
Acer saccharinum	Silver Maple	MT, T			
Acer saccharum	Sugar Maple	T	MT	VS	
Acer sieboldianum	Siebold Maple	MT			
Acer spicatum	Mountain Maple	VS			
Acer tataricom	Tatarian Maple	VS			
Acer velutinum	Velvet Maple	VT			
Aesculus hippocastanum	Common or White Horsechestnut	VT		VT, S	
Ailanthus attissima	Tree of Heaven	VT		MT, VT	
Alnus spe	Alder			MT	
Alnus glutinosa	European Alder	T, MT		MT	
Alnus hirsuta	Manchurian Alder	T			
Alnus incana	Speckled Alder	MT	VS	VS,S,VS	
Alnus rugosa	Speckled Alder	MT		S	
Amelanchier asiatica	Asian Serviceberry	VS			

TABLE 33: SALT TOLERANCES OF TREES AND SHRUBS (Cont'd)

LATIN NAME	COMMON NAME	Spray	Soil		General	COMMENTS
			Na	Cl		
Amelanchier canadensis	Shodblow Serviceberry				S	
Amelanchier grandiflora	Apple Serviceberry	VS				
Amelanchier laevis	Allegany Serviceberry	VS				
A. ovalis	Garden Serviceberry	T				
A. spicata	Dwarf Serviceberry	S				
Arctostaphylos uva-ursi	Bearberry	T				Prefers sandy soils. Can be difficult to transplant. Vigorous spreader. No special attention required. No insect or disease problems.
Aronia arbutifolia	Red Chokecherry				MT	
Aronia melanocarpa	Black Chokecherry				MT	
Artemisia abrotanum 'Nara'	Dwarf Southernwood				T	Requires reasonably fertile soil tolerates alkaline soils. Require little care. Some dying out due to disease.
Atriplex species	Salt Bush				T	
Atriplex patola (hastata)					VT	Needs moist, fairly saline soils
Baccharis halimifolia	Eastern Baccharus Groundsel-Bush				VT	
Berberis species	Barberry				VS	
Berberis aggregate	Salmon Barberry	S				
Berbaris beaniana	Beans Barberry	T				
Berberis bretschneideri	Purpleberry Barberry	VS				
Berberis dictyophylla	Chokleaf Barberry	VS				
Berberis dielsiana "Compacta"	Dwarfdiels Barberry	VS				
Berberis fendleri	Colorado Barberry	MT				
Berberir gagnepaini	Black Barberry	VS				
Berberis giraldii	Girald Barberry	VS				
Berberis hookeri	Hookers Barberry	VS				
Berberis julianae	Wintergreen Barberry	VS				
Berberis koreana	Korean Barberry	MT				
Berberis oblonga	Bigflower Barberry	MT				

TABLE 33: SALT TOLERANCES OF TREES AND SHRUBS (Cont'd)

LATIN NAME	COMMON NAME	NaCl			COMMENTS
		Spray	Soil	General	
Berberis thibetica	Thibetan Barberry	VS			
Berberis thunbergii	Japanese Barberry	VS			Available. Woody ornamental. Needs regular cultivation.
Berberis t. atropurpurea	Redleaf Ji Barberry	T			
Berberis tischleri	Tischler Barberry	VS			
Berberis vulgaris	Common Barberry	S			
Betula species	Birch	VS	MT	MT,VS	
Betula alba	White Birch			S	
Betula alleghaniensis	Yellow Birch			T	
Betula davoriea	Dahuvian Birch			VS,VS	
Betula ermannii	Ermans Birch	MT			
Betula humilis		S			
Betula lenta	Black Birch			T	
Betula papyrifera	Paper or Canoe Birch	MT		S,T	
Betula pendula	European Birch	MT	MT		
Betula populifolia	Cray Birch	MT		T	
Betula pubeicers		VS			
Betula schmidtii	Schmidts Birch	VS			
Buxus microphylla koreana	Koreana Boxwood			VS	Will not withstand roadside environments
Buxus semperrirens	Common Box		VS	VS,VS,S	
Callistemon lanceblatus	Bottle Brush		T		
Caragana arborescens	Siberian pea-tree	VT	VT,T	T	
Caragana frutex	Russian Peashrub			T	Large, woody shrub. Available
Carpinus betulus	European Hornbean	VS,S	VS	VS,VS	
Carpinus betulus quercifolia	Oakleaf Hornbean	S			
Carpinus caroliniana	American Hornbean			S,VS	
Carya species	Hickory			S	
Carya ovata	Shagbark Hickory	T		VS	
Carya pecan	Pecan			S	
Castanea dentata	American Chestnut	S			
Catalipa speciosa	Catalpa	MT			

TABLE 33: SALT TOLERANCES OF TREES AND SHRUBS (Cont'd)

LATIN NAME	COMMON NAME	Spray	Soil	General	COMMENTS
		Na Cl			
Celastrus orbiculata	Oriental Bittersweet				Needs good soil on banks
Celtis caucasica	Caucasian Hackberry	VS			
Cercis caradensis	Eastern redbud			MT	
Chaenomeles lagenaria	Flowering Quince	S			
Chamaecyparis pisifera	Swara False/cypress	S		MT	
Clematis orientalis				S	Not hardy enough for roadside use
Clematis panicubta				S	Not hardy enough for roadside use
Clematis tangutica				S	Not hardy enough for roadside use
Clematis texensis				S	Not hardy enough for roadside use
Clematis virginiana	Virginsbower				Ground cover, best in full sun. Available
Clethra alnifolia	Summersweet Clethra Sweet Pepper Bush			S	
Colutea arborescens	Bladder-senna	T			
Colutea persica	Persian Bladder-senna				Not Hardy
Comptonia peregrina	Sweetfern			T	Excellant, native, ground cover. Acid soils and full sun. Available
Condalia spathula	Knifeleaf Condalia			VT	
Cornus alba	Tatarian (Squawbush) Dogwood	S			
Cornus alba 'Kesselringii'	Purpletwig Dogwood	VS			
Cornus alba 'Siberica'	Siberian Dogwood	VS		T	
Cornus alba 'Spaethii'	Yellowedge Dogwood	VS			
Cornus amomum	Silky Dogwood	VS			
Cornus florida	Flowering Dogwood			T	
Cornus mas	Cornelian Cherry	VS			
Cornus racemosa	Cray Dogwood	S		MT	
Cornus sanguinea		VS,S		VS	
Cornus stelonifera	Redosier Dogwood	VS,S		MT	Spreading shrub or hedge. Adapted to all but dry climates
Corylus species	Filbert		VS	S	
Corylus americana	American Filbert	VS			

TABLE 33: SALT TOLERANCES OF TREES AND SHRUBS (Cont'd)

LATIN NAME	COMMON NAME	NaCl			COMMENTS
		Spray	Soil	General	
Corylus arellana	Common Filbert	VS,VS,S	VS	VS,VS,VS	
Corylus colurnaides	Colurnoid Filbert	VS			
Corylus cornuta	Beaked Filbert	VS			
Corylus sieboldiana	Japanese Filbert	VS			
Cotoneaster diraricata	Spreading Cotoneaster			S	
Cotoneaster integerrimus	European Cotoneaster	VS			
Crataegus species	Hawthorn	S	T	S,T	
Crataegus coccinea (intricata)	Thicket Hawthorn			T	
Crataegus coccinoides	Kansas Hawthorn	S			
Crataegus crusgalli	Cockspur Hawthorn	VS		T	
Crataegus grignonensis		VS			
Crataegus intrecata	Thicket Hawthorn	VS			
Crataegus lavallei	Lavalle Hawthorn	S			
Crataegus mollis	Downy Hawthorn			T	
Crataegus monogyra	Singleseed Hawthorn	S,S,VS		MT,VS	
Crataegus oxyacantha	English Hawthorn	S,S,VS		VS	
Crataegus phaenopyrum	Washington Hawthorn			T	
Crataegus prunifolia	Plumleaf Hawthorn	VS			
Crataegus punctata	Dotted Hawthorn	S			
Crataegus sanguinea	Redhaw Hawthorn	S			
Crataegus sorbifolia	Sorbus Hawthorn	VS			
Cryptomeria japonica	Japanese Cryptomeria			MT	
Cydonia oblonga	Quince	MT			
Cytisus purpurea procumbens	Prostrate Purple Broom			S	Recommended only where it can be maintained.
Cytisus species	Broom			MS	
Dievilla lonicera	Dwarf Bush Honeysuckle			VT	Recommended on dry banks-all soils Hardy in full sun or shade
Diervilla rivularis	Georgia Bush Honeysuckle			VT	More vigorous than Dwarf Bush Honeysuckle. Available

TABLE 33: SALT TOLERANCES OF TREES AND SHRUBS (Cont'd)

LATIN NAME	COMMON NAME	Na Cl			COMMENTS
		Spray	Soil	General	
Dervilla sessilifolia	Southern Bush Honeysuckle			VT	More vigorous than Dwarf Bush Honeysuckle. Available
Elaeagnus angustifolia	Russian Olive	T,T,T	T,T	MT,VT VT,VT	
Elaeagnus commutata	Silverberry	VT			
Elaeagnus ebbingei		VS			
Elaseagnus multiflora	Cherry elaeagnus	MT			
Elaeagnus pungens reflexa		VS			
Elaeagnus pungens simoni		VS			
Elaeagnus umbellata	Autumn Elaeagnus	VS		T	
Eucalyptus globulus	Tasmanian Blue Eucalyptus			MT	
Eucalyptus robusta	Beakpod Eucalyptus			MT	
Euonymus alatus	Winged Euonymus (Burningbush)	T	VS,VS	T,VS	
Euonymus europaeus	European Euonymus (Spindletree)	S		T	
Euonymus fortunei vegetus	Bigleaf Wintercreeper			S	
Euonymus latifolius	Broadleaf Euonymus	S			
Euonymus nanus	Dwarf Euonymus	VS			
Euonymus verrucosus	Wartybark Euonymus	VS			
Eupatorium coelertinum	Mistflower Eupatorium				
Fagus grandifolia	American Beech	MT,VS	MT	VS,S	
Fagus orientalis	Oriental Beech	VS			
Fagus silvatica	European Beech	VS,S	VS	VS,MT VS,S	
Fagus silvatica laciniata	Cutleaf European Beech	VS			
Fagus silvatica quericifolia	Oakleaf European Beech	VS			
Forsythia 'Arnold Dwarf'	Arnonld Dwarf Forsythia			S	Needs fertile soils
Forsythia 'Bronxensis'	Bronx Forsythia			S	Not Hardy
Forsythia Hybrid	Hybrid Forsythia			S	Not Hardy
Forsythia intermedia	Border Forsythia	MT			
Forsythia intermedia 'Spectabilis'	Spring Glory Forsythia		MT		
Fraxinus americana	White Ash	T			
Fraxinus angustifolia	Narrowleaf Ash	MT			

TABLE 33: SALT TOLERANCES OF TREES AND SHRUBS (Cont'd)

LATIN NAME	COMMON NAME	Spray	Soil	General	COMMENTS
		Na Cl			
Fraxinus excelsior	European Ash	T,T		MT	
Fraxinus hdotricha		S			
Fraxinus ornus	Flowering Ash	VT			
Fraxinus pennsylvanica lanceolata	Green Ash		S,MT MT	MT,TT VT	
Gleditsia japonica	Japanese Honeylocust		T,VT	T	
Halimodendron halodendron	Salttree (Siberian)	T		VT	
Hemerocallis fulva	Tawny Daylily			T	Hardy perennial lily-like plant. 3 feet high easily grown. Readily available
Hibisuc syriacur	Shrubalthea			T	
Hippohpae rhamnoides	Common Seabuck Thorn	MT,T MT		T,T	
Hydrangea macrophylla	Bigleaf Hydrangea			S	
Ilex aguifolium	English Holly	VS		MT	
Ilex crenatoa	Japanese Holly			S	
Ilex glabra	Inkberry			S	
Ilex opaca	American Holly			MT	
Ilex verticillata	Winterberry Black Alder		VS	MT,S	
Juglans species	Walnut			S	
Juglans nigra	Black Walnut	T	VS	VS	
Juglans regia	English or Persian Walnut	T		MT	
Juniperus species	Juniper	MT			
Juniperus chinensis pfitceriana	Pfitzer Juniper		T	T	Widely available, hardy.
Juniperus communis depressa	Prostrate Juniper			MT	Spreader, Needs further evaluation. Not too available
Juniperus conferta	Shore Juniper			VT	Excellent salt resistance; in some locations, not hardy
Juniperus horizontalis	Spreading (Creeping) Juniper			T	Prefers sandy dry soil. Requires little attention
Juniperus horizi 'Alpina'	Alpine Juniper				
Juniperus horizontalis	Andorra Creeping Juniper		MT,MT	T	

TABLE 33: SALT TOLERANCES OF TREES AND SHRUBS (Cont'd)

LATIN NAME	COMMON NAME	Spray	Soil	General	COMMENTS
		Na Cl			
Juniperus sabina 'Arcadia'	Arcadia Juniper				
Juniperus sabina 'Skandia'	Skandia Juniper			MT	Arcadia & Skandia
Juniperus virginiana	Eastern Red Cedar	MT	MT	MT,TT, T	
Kalmia latitolia	Mountain Laurel			MT	
Kolkwitzia amabilis	Beauty Bush	S			
Laburnum anagyroides	Golden Chain	VS			
Lantana camera	Lantara		MT		
Larix species	Larch			VS, VS	
Larix decidua	European Larch	T			
Larix larieina	Tamarock	T			
Larix leptolepis	Japanese Larch	T			
Lespedeza japonica intermedia	Japanese Lespedeza				
Ligustrum species	Privet	MT		MT, T	
Ligustrum amvrense	Amur Privet		T	MT	
Ligustrum ibotium	Ibolium Privet			MT	
Ligustrum obtusifolium regelionum	Regal Privet			T	
Ligustrum texanum	Texas Privet		MT		
Ligustrum vulgare	European Privet	MT,VS,S		S,VS	
Liriodendron tulipitera	Tulip Tree		VS		
Lonicera species	Honeysuckle	T		MT	
Lonicera amoena 'Alba'	White gotha Honeysuckle	S			
Lonicera caprifolium	Sweet Honeysuckle	S			
Lonicera coerulea	Sweetberry Honeysuckle	S			
Lonicera fragvantissima	Winter Honeysuckle			T	
Lonicera involucrata	Bearberry, Honeysuckle	VS			Not fully hardy
Lonicera japonica halliana	Halls Japanese Honeysuckle		MT,MT	T,MT, VT,T	
Lonicera ledebourii	Ledebour Honeysuckle	S			
Lonicera maackii	Amur Honeysuckle	S			
Lonicera morrowii	Morrow Honeysuckle	S		T	
Lonicera nigra		MT			

TABLE 33: SALT TOLERANCES OF TREES AND SHRUBS (Cont'd)

LATIN NAME	COMMON NAME	Spray	Soil Na Cl	General	COMMENTS
Lonicera periclymenum	Woodbine Honeysuckle	T			Not hardy
Lonicera purpusii	Purpus Honeysuckle	VS			
Lonicera syringantha	Lilac Honeysuckle	VS			
Lonicera tatarica	Tatarian Honeysuckle	VS	T	VT	
Lonicera xylosteum	European Fly Honeysuckl	MT,T		T	
Lycium chinensis	Chinese Waltberry			MT	Does not compete well with grasses and weeds
Lycium halimifolium (uulgare)	Matrimony Vine			VT,MT VT	
Malus species	Apple	S		S	
Malus species	Crabapple	MT		S	
Malus baccata	Siberian Crabapple		MT		
Malus silvestris	Apple		T		
Mespilus germanica	Medlar	VS			
Metaseguoia glyptostroboides	Dawn Redwood	VS			
Morus species	Mulberry		T	VT,T VT	
Morus alba	White Mulberry	VS,VS			
Myrica pennsylvanica	Northern Bayberry			VT,T	Semi evergreen shrub. Full sun. Available
Nerium oleander	Oleander		T		
Nyssa sylvatica	Black Tupelo			MT	
Olea europaea	Common Olive			T	
Ostrya japonica	Japanese Hophornbean	MT			
Pachistina canbyi	Canby Pachistina				
Pachysandra terminalis	Japanese Spurge			S	Suited only to protected, fertile sites. Acidic or neutral soils
Parthenocissus gvinguefolia	Virginia Creeper				
Picea abies	Norway Spruce	VS,MT	S	S	
Picea glauca	White Spruce	VS	MT,MT	VS	

TABLE 33: SALT TOLERANCES OF TREES AND SHRUBS (Cont'd)

LATIN NAME	COMMON NAME	Spray	Soil	General	COMMENTS
			Na Cl		
Picea pungens	Blue Spruce	VT	VS,MT	VS	
Pinus cembra	Swiss Stone Pine	VS			
Pinus divaricata	Jack Pine	T			
Pinus mugo mughus	Mugo Pine	T		T	
Pinus nigra	Austrian Pine	T		T	
Pinus ponderosa	Ponderosa Pine		MT,MT	MT,T,T	
Pinus resinosa	Red Pine	VS		MT,VS	
Pinus strobus	White Pine	VS	S	VS	
Pinus sylvestris	Scotch Pine	VS,VS		MT	
Pinus thumbergi	Japanese Black Pine			VT	
Pittosporum spp	Pittosporum		MT		
Platanus acerifolia	London Planetree	S		VS,MT	
Populus species	Poplar	T	MT	S	
Populus acuminata	Lance Leaf Poplar			T	
Populus alba	White Poplar	T	T	VT,T	
Populus alba nirea	Silver Poplar	T	T	VT,VT	
(alba acerifolia)	Silver Poplar				
(alba arembergica)	Silver Poplar				
(alba argentea)	Silver Poplar				
Populus angustifolia	Narrow Leaf Poplar			T	
Populus balsamifera (deltoides missoriensis)	Southern Poplar			T	
Populus canadensis	Carolina Poplar	VT			
Populus canescens	Gray Poplar	VT	T	VT,VT	
Populus deltoides	Eastern Poplar(Cottonwood)	VT	MT	T	
Populus fremontii	Fremont Cottonwood			T	
Populus grandidentata	Largetooth Aspen	MT		T	
Populus laurifolia	Laurel Poplar			VS,VS	
Populus nigra	Black Poplar	T		MT	

TABLE 33: SALT TOLERANCES OF TREES AND SHRUBS (Cont'd)

LATIN NAME	COMMON NAME	Spray	Soil	General	COMMENTS
		Na Cl			
Populus nigra "Italica"	Lombardy Poplar	MT	VS	S,VS	
Populus sargesti	Plains Poplar			T	
Populus tremula	European Aspen			VT,S	
Populus tremuloider	Quaking Aspen	MT,MT		VT,ST	
Populus trichocarpa	California Poplar			T	
Potentila tridentata	Nineleaf Cinquefoil			S	Adapted to poor rocky and sandy soils. Good evergreen ground cover. Available
Prunus species	Prune			S	
Prunus armeniaca	Apricot	S	T	VT,VT	
Prunus arium	Mazzard Cherry	MT		T	
Prunus mahaleb	Mahaleb Cherry	VS			
Prunus maritima	Beach Plum			T	
Prunus padus	European Bird Cherry	T		MT,T	
Prunus persica	Peach			S	
Prunus serotina	Black Cherry	VS,S,VS		T	
Prunus spinosa	Blackthorn	S		T	
Prunus virginiana	Chokecherry	T			
Pseudotsuga menzesii	Douglas Fir	MT	VS,MT	VS	
Pseudotsuga taxitolia	Common Douglas Fir			VS,MT	
Puccinellia distans (L)				VT	
Pyracantha species	Pyracantha		MT	S	
Pyracantha atalantoides	Gibbs Firethorn	VS			
Pyracantha coccinea	Scarlet Firethorn	VS	MT		
Pyracantha crenatoserrata	Chinese Firethorn	VS			
Pyrus species	Pear	MT		S	
Pyrus baccata	Siberian Crab			MT,MT	
Pyrus padus	European Bird Pear			MT	
Quercus species	Oak			T,T	
Quercus alba	White Oak	VS	VT,T VT	VT,T, VT	
Quercus bicolor	Swamp White Oak		VT	MT,T	
Quercus borealis	Northern Red Oak		VT	MT,T	

TABLE 33: SALT TOLERANCES OF TREES AND SHRUBS (Cont'd)

LATIN NAME	COMMON NAME	Spray	Soil	General	COMMENTS
		Na		Cl	
Quercus cerris	Turkey Oak	S			
Quercus coccinea	Scarlet Oak			MT,T	
Quercus heterophylla	Bartram Oak	S			
Quercus libani	Lebanon Oak	VS			
Quercus macranthera		MT			
Quercus macrocarpa	Bur Oak	MT,S		T	
Quercus muehlenbergii	Yellow Chestnut Oak	VS			
Quercus palustris	Pin Oak	S		MT	
Quercus petraea	Durmast Oak	VS			
Quercus pyrenaica	Pyrenees Oak	VS			
Quercus robur	English Oak	S	T,VT	VT,VT	
Quercus rubra	Southern Red (Falcata)	S,T	T	VT,T	
	Eastern Red (Borealis maxima)	S,T	T	VT,T	
	Swamp Oak	S,T	T	VT,T	
Quercus sessilifora	Durmast Oak)Petraca)			T	
Rhamnus species	Buckhorn			MT	
Rhamnus catharticus	European Buck	MT,VT			
Rhamnus crenatus	Oriental Buck	MT			
Rhamnus davurica	Dahurian Buckthorn	T			
Rhamnus frangula	Alder Buckthorn	MT,MT			
Rhamnus infectorious	Persianberry Buckthorn	MT,MT			
Rhamnus utilis	Chinese Buckthorn	VS			
Rhus aromatica	Fragrant Sumac			T	Dense growth. Accustomed to dry soils. Not commonly available
Rhus copallina	Flameleaf Sumac			VT	
Rhus glabra	Smooth Sumac			T	Woody, spreading shrub. Wide variety of soils. Has ability t occupy poor soil
Rhus glabra cismontana	Rocky Mountain Sumac				Similar to but less hardy than Smooth Sumac
Rhus trilobata	Squawbush		T,T	VT,VT, VT	

TABLE 33: SALT TOLERANCES OF TREES AND SHRUBS (Cont'd)

LATIN NAME	COMMON NAME	Spray	Soil	General	COMMENTS
		Na		Cl	
Rhus typhina	Staghorn Sumac	T		T	
Ribes alpinum	Alpine currant	T,MT,T		T	
Ribes americanum	American Black Currant	MT			
Ribes aureum	Golden Currant	T			
Ribes diacanthum	Siberian Currant	T			
Ribes divaricatum	Straggly Gooseberry	MT			
Ribes giraldii		VS			
Ribes gardonianum	Gordon Currant	T			
Ribes Magdalenae		T			
Ribes migrum	European Black Currant	VS		MT,MT	
Ribes niveum	Snow Gooseberry	T			
Ribes sanquineum	Winter Currant	S			
Robina species	Locust			VT,VT,T	
Robinia lispida	Roseacacia	Locust		MT	
Robinia pseudoacacia	Black Locust	VT,VT	T	VT,VT,T	
Robinia pseudoacacia "Pyramidalis"	Pyramid Locust	VT			
Rosa amblyotis	Kamchatka Rose				Viborous suckering shrub rose. Not commercially available
Rosa canina		S,VS,S			
Rosa multiflora	Japanese Rose or Multiflora Rose		S,S,VS	VS,VS, MT	
Rosa nitida	Shining Rose			MT	
Rosa rubiginosa	Sweetbriar	VS			
Rosa rugosa	Rugosa Rose	T		MT,T	
Rosa wichuraiana	Wichura or Memorial Rose		MT	MT,T	
Rubus allegheniensis	Allegheny Blackberry			T	A scrambling, thorny plant. Adapted to many soils. Available from wild stock
Rubus flagellaris	Northern Dewberry			S	Hardy native
Rubus fructicasus	European Blackberry	S,VS			
Rubus laciniatus	Cutleaf Blackberry			S	Inadequately hardy

TABLE 33: SALT TOLERANCES OF TREES AND SHRUBS (Cont'd)

LATIN NAME	COMMON NAME	Na Cl			COMMENTS
		Spray	Soil	General	
Rubus parvitolius	Japanese Trailing Raspberry			T	Hardy ground cover. Soil must be fertile
Rubus rosendahli	Rosendahl Dewberry			S	Rare native; sandy, acidic soils, full sun
Salix alba	White Willow	T		T	
Salix alba calva	Pyramidal Weeping Willow			T	
Salix alba tristis	Golden Weeping Willow	MT		T	
Salix alba ritellina	Yellowstem Willow	VS	T,MT	T,T,VS	
Salix amygdalina	Peach-leaf Willow	T			
Salix aurita	Roundear Willow	MT			
Salix babylonica	Babylon Weeping Willow			VT,T	
Salix caprea	Great Willow	MT,MT		MT	
Salix daphnoides	Daphne Willow	T			
Salix fragilis	Brittle Willow	T			
Salix nigra	Black Willow	T			
Salix pentandra	Laurel Willow	MT			
Salix purpurea	Purple Osier Willow		T,VT	VS,VS,T	
Salix purpurea nana	Artic Blue Willow Blue Willow			VS,VS	
Salix purpurea lambertiana	Lambert Purpleasier Willow	T			
Salix tristis	Dwarf Gray or Pussy Willow			VS	Low shrubby native occuring on sandy acidic soils. Full sun.
Salix vitellina	Golden Willow			MT,T	
Sambucus canadensis	American Elder	S		MT	
Sambucus nigra	European Elder	S		MT	
Sambucus racemosa		VS,S,S			
Sapirdus species	Soapberry			VT	
Sheperdia argentea	Silver Buffalo Berry	T,MT,T			
Sheperdia canadensis	Russet Buffalo Berry			T	
Sophora japenica	Japanese panoda Tree	VS			
Sorbus species	Mountain Ash	T			
Sorbus aria	White Beam Mountain Ash	T			

TABLE 33: SALT TOLERANCES OF TREES AND SHRUBS (Cont'd)

LATIN NAME	COMMON NAME	Spray	Soil	General	COMMENTS
		Na		Cl	
Sorbus aucuparia	European Mountain Ash	VS		S	
Sorbus commixta	Korean Mountain Ash	MT			
Sorbus decora	Snowy Mountain Ash	T			
Sorbus hybrida	Oakleaf Mountain Ash	S			
Sorbus intermedia	Swedish Mountain Ash	VS			
Sorbus japanica	Japanese Mountain Ash	T			
Sorbus koehneana	Koehnes Mountain Ash	VS			
Sorbus latifolia		S			
Sorbus pohuashanensis		VS			
Sorbus rufo-ferruginea	Flameberry Mountain Ash	VS			
Sorbus sambucifolia	Siberian Mountain Ash	VS			
Sorbus serotina		T			
Sorbus torminalis	Wild Service Tree	S			
Sorbus vilmorinii	Vilmorin Mountain Ash	VS			
Spiraea species	Spirea Vanhouttii			VS	
Spiraea arguta compacta	Dwarf Garland Spirea				Needs fertile, cultivated site. Available
Spiraea billiardi	Billiard Spirea				Spreading shrub. Available
Spiraea x bumalda	Bulmalda Spirea	S			
Stephanandra incisa	Dwarf Cutleaf Stephanandra				Low, arching plant. Limited availability
Stewartia serrata		S		T	
Symphoricarbus albus	Snowberry	MT,T		T	Available. Not adequately tested
Symphoricarpus albus racemosus	Common Symphoricarpes			T,T	
Symphoricarpus x chenaulti	Chenault Coralberry	VS		S	Not hardy
Symphoricarpus x chenaulti, Hancock	Hancock Coralberry	VS		S	Not fully hardy
Symphoricarpus occidentalis	Wolfberry			T	Hardy. Easily propagated. Adapted to all soils. Full sun
Symphoricarpus orbiculatus	Coralberry	VS			
Syringa amurensis japonica	Japanese Tree Lilac	T			
Syringa vulgaris	Common Lilac	VS,T			
Tamarix species (pentardra)	Tamarix (5 Stamen Tamarix)	T		VT,VT	
Tamarix gallica	French Tamarix		T,T	VT,VT	

TABLE 33: SALT TOLERANCES OF TREES AND SHRUBS (Cont'd)

LATIN NAME	COMMON NAME	Spray	Soil	General	COMMENTS
		Na		Cl	
Tamarix hispida	Kashgar Tamarix			VT,VT	
Tamarix pallasii				VT	
Taxus species	Yew	S			
Taxus baccata	English Yew	VS			
Thuja species	Arboruitae			T	
Thuja occidentalis	Eastern or American Arbovitae	S	MT	T	
Thuja orientalis	Oriental Arborvitae			T	
Tilia species	Linden			VS	
Tilia americana	Basswood	MT		VS	
Tilia cordata	Little Leaf Linden	T	VS,VS	MS,S,VS	
Tilia euchlora	Crimean Linden	S			
Tilia platyphylla	Bigleaf Linden	T			
Tsuga canadensis	Canada Hemlock	VS	VS	VS	
Tsuga heterophylla	Western Hemlock	MT			
Ulmus species	Elm			MT,S	
Ulmus americana	American Elm	T	VT	T,VS	
Ulmus campestris	European Elm		T	VT,VT	
Ulmus (carpinifolia)	Smooth-leafed Elm	S,MT,MT		VT,MT	
Ulmus glabra	Scotch Elm	T,T		T	
Ulmus hollandica major	Dutch Elm			MT	
Ulmus laevis	Russian Elm	MT			
Ulmus parrifolia	Chinese Elm			T	
Ulmus procera	English Elm			T	
Ulmus pumila	Siberian Elm	T		VT,T	
Ulmus pumila aborea	Narrow Siberian Elm	VS			
Vaccinium angustifolium	Lowbush Blueberry				Native low shrub. Hardy once established. Requires moisture and acidic soils. Available
Vaccinium corymbosum	Highbush Blueberry			VS	Not hardy. Acidic soils, full sun.
Vaccinium corrymbosum x angustifolium	Hybrid Blueberry			VS	Acidic soils, full sun. Limited value.

TABLE 33: SALT TOLERANCES OF TREES AND SHRUBS

LATIN NAME	COMMON NAME	Spray	Soil Na	Soil Cl	General	COMMENTS
Vaccinium nurtilloides	Velvet Leaf Blueberry				MS	A native species on acidic soils. Too difficult to grow
Vaccinium vitis-idaea	Cowberry				T	
Vilburnum species	Viburnums		VS,VS		MT	
Vilburnum burkwosdi	Burkwood Viburnum				MT	
Viburnum carlesi	Fragrant Viburnum				MT	
Viburnum cassinoides	Witherod Viburnum				MT	
Viburnum dentatum	Arrowwood Viburnum				MT	
Viburnum lantana	Wayfaringtree Viburnum	S				
Viburnum lentago	Nannyberry Viburnum				MT	
Viburnum molle	Kentucky Viburnum	S				
Viburnum opulus	European Cranberry Bush	S,T				
Viburnum prunifolium	Blackhaw Viburnum				S	
Viburnum sieboldi	Siebold Viburnum				MT	
Viburnum tomentosum	Doublefile Viburnum				MT	
Vinca major	Greater Periwinkle					
Vinca minor	Common or Lesser Periwinkle				MT	
Weigela 'Eva Rathke'	'Eva Rathke' Weigela		MT			
Xanthorhiza simplicissima	Yellowroot				VS	Needs moist soil. Acidic or neutral soils
Xylosma congestum	Xylosma		MT			
Yucca filamentosa	Adams Needle		MT			
Zelkova serrata	Japanese Zelkova				MT	

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